FACTORS INFLUENCING THE CHEMICAL ANATOMY OF THE GROWING FOWL

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A Thesis presented for the Degree of
Doctor of Philosophy for the
University of Edinburgh in the
Faculty of Medicine

NOVEMBER 1972

ABSTRACT

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1. The growth pattern of the organs of the heavy hybrid brown egg laying bird has been studied. Ninety-six birds were examined in groups of six at intervals of about 2 weeks from 4 weeks to 30 weeks with a final group at 76 weeks. The organs studied were heart, liver, kidneys, adrenals, spleen, ovary, oviduct, gizzard and gut.

2. The study was directed mainly at the changes occurring at the onset of sexual maturity. The ovary and oviduct seem to develop together over a period of 14 days in a given bird, but in an apparently homogenous group of birds the onset of sexual maturity may vary from the age 19 weeks to 24 weeks or more.

3. There is a marked change in the physiology underlying the growth of the bird at the time of sexual maturity. This is reflected in changes in muscle mass, adrenal mass, fat mass and spleen mass.

4. Parallel with these studies a chemical analysis of the bodies of a light hybrid white egg laying bird was undertaken in 96 birds killed at the same intervals as those for the anatomical studies.

5. Water, fat, protein (N x 6.25), Na, K, Mg, Ca, P, Cl and Fe content of skeletal muscle and total body were

estimated. As indicated in the anatomical studies sexual maturity is a period of "stress" for the bird. Cell mass and fat mass were found to diminish during this period. However, Ca and Fe deposits are increased in anticipation of the loss of these substances to the egg.

6. There is a striking parallelism between liver fat composition and body fat composition. The correlation between amounts of liver fat and of body fat is positive and the correlation coefficient is 0.643 which is highly significant ($P < 0.001$). ~~This correlation suggests that a liver biopsy provides a sufficient measure for body fat.~~ (% body fat = 0.663 x % liver fat + 70.4).

7. Because of the overall changes in the growth pattern due to the "stress" of egg production, a nonspecific mild stress was studied in the newly hatched bird which should be highly vulnerable at this time because of the rapid growth rate. Four hours of exposure to $10^{\circ}C$ was sufficient to cause profound changes in growth for at least 14 days.

8. The changes in growth pattern were not uniform. White muscle was affected more than the red muscle, and fat deposits were affected most of all. Bone growth was also affected but not so markedly.

9. The mineral analyses indicate that K dilution techniques

provide a useful means of measuring cell mass as do Mg dilution, and those given results are consistent with dissections. The K dilute techniques may be best for in vivo cell mass determinations.

10. X-ray fluorescence spectrometry analysis has been found to be ~~the only~~ a reliable technique for estimating the mineral content of large numbers of biological materials in a short time.

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1. INTRODUCTION

1. INTRODUCTION

The interest in the chemical composition of the animal body including man has been the subject of research for many years. The chemical composition of the human body has been determined by the chemical analysis of cadavers (Mitchell, 1945; Widdowson, McCance and Spray, 1951 and Widdowson and Dickerson, 1964). Indirect methods have also been used for measuring different chemical substances in the living human body using radioisotopes and dilution methods (Elkinton and Danowski, 1955 and Moore, 1965). It is not usually possible to determine the chemical composition of healthy human bodies from birth to adult human life in the same way as is possible using animal bodies. Therefore, most of the information concerning the chemical anatomy of the human body has been derived from direct or indirect chemical analysis of animals of all species and ages.

In the work presented in this thesis the domestic fowl (Gallus domesticus) has been employed to study the chemical anatomy of the body from hatching to adult life. Because skeletal muscle comprises the largest cell mass in the body, particular attention has been given to muscle tissue throughout this work. Our knowledge and information about different chemical substances present in the living animal body, including man, has been greatly enlarged by modern science today. This is because powerful, new methods and

techniques of analysis have been developed during the last century which have greatly advanced our knowledge of body composition. The chemical composition of the body changes markedly with growth and development of the animal.

Robinson (1952) and Widdowson and McCance (1956b) reported that development and growth are associated with an increase in the cell constituents and a decrease in the extracellular materials. Brody (1945) said that growth is a biological synthesis used for the production of new biochemical units and it is the part of development concerned with increases in living substances. He pointed out that one or all three processes are involved in this aspect, these are (1) incorporation of material taken from the environment, (2) cell multiplication (hyperplasia) and (3) cell enlargement (hypertrophy). The importance of muscle mass has been pointed out by Cahill and Owen (1970) who stated that muscle mass has been important for the survival of man in primitive life when struggle for survival depended upon hunting. It was necessary for man to be not only extremely mobile and to be able to preserve his muscle mass under all conditions, but in extremes his muscle mass can act as an important source of fuel. The skeletal muscles considered in this work are the breast and thigh muscles of the fowl. These muscles are easily identified and represent a large fraction of white and red muscle cells of the body. According to George and Berger (1966) the differentiation of these two muscles has been based on the amount of myoglobin content

of the muscles. The myoglobin-containing fibres are very few in number, whereas those that lack myoglobin are predominant in the breast muscle. On the other hand the thigh muscle is mainly made of myoglobin-rich fibres.

This work has been carried out in two phases as follows:

(1) The body of the fowl was dissected into its gross morphological components. These are breast muscle, thigh muscle, liver, kidneys, adrenals, heart, spleen, ovary, oviduct, gizzard and gut. Breast, thigh and liver were analysed for different chemical composition while the rest of the body components were analysed for water and dry matter.

(2) The dissected carcass of the fowl was ground to a powder after the breast and thigh muscles were removed. The ground material was then thoroughly mixed to form a homogenous mass from which aliquots were taken for chemical analysis.

The procedures by which this work has been accomplished are as follows:

1. Growth rate, in terms of total body weight and the constituents fat, protein (N x 6.25) and water.
2. Growth was broken down into anatomical aspects which comprised heart, liver, kidneys, adrenals, spleen, ovary, oviduct, gizzard and gut, and into chemical aspects which included breast muscle, thigh

muscle, liver and the body carcass*.

3. Chemical anatomy of the body was considered by determining certain body minerals by chemical analysis. Consequently, some assessment could be made of the various compartments of the body, for example, cell mass, skeletal mass and extra-cellular fluid. This is more meaningful than procedure 1. because it gives a more direct measure of cell growth and it is also of some practical interest in that some idea of muscle mass can be deduced which is of value in a carcass destined for use as meat.

* Body carcass mentioned in this work represents that part of the bird remaining after breast and thigh muscles have been dissected.

2. GENERAL REVIEW OF LITERATURE

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The chemical composition of the body, in man or animal, is not in a stagnant state; it is constantly changing as growth and development progress. The composition of each of the component parts of the body is also changing. The changes in the chemical composition of the body do not occur as a result of growth and development only, but also as a result of disease and nutritional abnormalities. Generally speaking, undernutrition leads to a decrease of fat and some cellular materials and to an increase in the proportion of extracellular fluid of the body (Widdowson and Dickerson, 1964). Passmore (1961) stated that the chemical composition of the human body is not fixed but is constantly varying and is dependent upon the proportion of fat to carbohydrate in the metabolic mixture that the human body is burning. The author said that when the body is running on carbohydrates, 2 to 4 litres of water more is required than when the body is running on fat.

The chemical anatomy of the human body has been discussed by Passmore and Draper (1970) who stated that body water can vary from 50% to 70% of body weight in health depending upon how fat the subject is. They also suggested that the active cell mass may be defined by the equation:

Cell mass = total body weight - body fat - extracellular fluid - skeletal and protein minerals.

The mineral composition of the human body was reviewed and discussed by the same authors. In health in a 65 kg man the sodium levels in the plasma lie between 140 to 150 m.equiv./litre: the cells contain 3500 m.equiv. of potassium or more, while the extracellular fluid contains less than 100 m.equiv. Muscle cells contain about 4/5 of all potassium in the body. There is very little potassium in the bones. The adult human body contains about 30 g of magnesium, most of which is found in the bones, and 1.2 kg of calcium of which the vast majority is incorporated in the skeleton. There is about 40 m.equiv. in the extracellular fluid and a very small amount in the intracellular fluid.

Widdowson, McCance and Spray (1951) reported the results of their work on a human body which had been chemically analysed. Fat, nitrogen, calcium, phosphorus, magnesium, sodium, potassium, iron, zinc and copper were determined. The values obtained were as follows:

725 gm of water per kilogram fat-free tissue
31.1 gm of total nitrogen per kilogram fat-free tissue
92.0 m.equiv. of Na per kilogram fat-free tissue
71.5 m.equiv. of K per kilogram fat-free tissue
21.3 gm of Ca per kilogram fat-free tissue
14.0 gm of P per kilogram fat-free tissue
0.48 gm of Mg per kilogram fat-free tissue
87.5 mg of Fe per kilogram fat-free tissue
1.6 mg of Cu per kilogram fat-free tissue
33.3 mg of Zn per kilogram fat-free tissue

These values obtained by Widdowson et al (1951) were

determined from the analysis of a male human subject aged 25 years.

The chemical analysis of a normal healthy human body from birth to adult life is usually impossible to obtain since the normal healthy person does not die unless as a result of accident or suicide. In addition, problems may arise in handling such large quantities of material which may exceed the capacities of most laboratories unless special arrangements could be made. It is, therefore, essential to continue the research in this field on animals other than man. Mammals, birds and other animals have been subjected to many experiments to find the chemical changes in composition that occur during the growth and development of the animal. Investigations into this subject were started as early as 1800 when Von Bezold (1857) stated that there was a decrease in water content of the body beginning with the development of the embryo and continuing up to the height of early growth. There was also an increase in the solid organic material and ash during growth and development. Moulton (1923) studied the effect of age on the chemical development of mammals. He found that the proportion of water in the fat-free animal tissue rapidly decreased from conception to birth. Nitrogen and ash were considerably increased. Chanutine (1931) found that fat, total nitrogen and ash increased during the growth of the rat. There was a marked increase in the percentage concentration of ether extract and ash during

the first 20 days after birth. Spray and Widdowson (1950) found that in rat, cat, rabbit and pig there was a large increase in the percentage of fat in the body after birth accompanied by a decrease in the percentage of water.

From the point of view of body composition, skeletal muscle is the largest cell mass of the body. It contains a significant potential fuel (protein) which is essential for survival. It contains also other important elements such as potassium and phosphorus. Attention has been focused on the skeletal muscle in the way in which the muscle grows and develops and to the chemical changes that take place as the animal matures, and also to the contribution made by the skeletal muscle to the total body composition. The effect of growth on the skeletal muscle was investigated by Yennet and Darrow (1938). They pointed out that the muscle growth was associated with a decrease in the concentration of sodium and chloride and an increase in the concentration of nitrogen, phosphorus and potassium. There was little change in the percentage of the total water of the muscle. The changes in the chemical composition of the skeletal muscle has been described by the same authors as a result of a change in the distribution of water between the intracellular and extracellular compartments caused by the growth of the muscle fibres. It has been stated by Wilmer (1940) that 25% of the weight of the new-born baby and 43% of the weight of a man was contributed by the skeletal muscle. Forbes, Cooper and Mitchell (1953) found

that in the adult human subject -

50.5%	of	total	body	water	was	contributed by	skeletal muscle
40.0%	"	"	weight		"	"	"
13.5%	"	"	fat		"	"	"
46.8%	"	"	protein (N x 6.25)		"	"	"
7.4%	"	"	ash		"	"	"

The proportion which the skeletal muscle mass contributes to the body in the undernourished animal was reported by Jackson (1915) who found that the proportionate loss of muscle weight was greater than the body as a whole. Addis, Poo and Lew (1936) studied the loss of protein by various organs and tissues of the fasting rat. They found that when rats were fasted for seven days, muscle, skin and skeleton had contributed 62% to the total protein lost by the body of which muscle was probably the major source. Liver and spleen gave only 16% and 14% respectively to the total loss.

Manery and Hastings (1939) presented an account for the distribution of electrolytes in mammalian tissues. They stated that, in the skeletal muscle of the rabbit, chloride and most of the potassium were confined to separate cellular phases. Sodium and chloride were dominant ions of the extracellular phase and potassium a dominant ion of the intracellular phase. They pointed out that skeletal muscle, liver, spleen, heart, brain and kidney contained a large proportion of chloride-free cells, and the blood, connective tissues, gastric mucosa and testes had a large proportion

of chloride-containing cells. The fall in water and the increase in the intracellular constituents during the development of the skeletal muscle had been reported by Robinson (1952), McCance and Widdowson (1956a) and Widdowson and McCance (1956b). They agreed that the fall in the water content of the muscle was accompanied by a fall in the concentration of extracellular ions, sodium and chloride, while total muscle nitrogen, potassium and magnesium were increased. The chicken skeletal muscle had been analysed for chemical composition during development by Barlow and Manery (1954). They found that the breast muscle of a chick of three to four days old had about 9% more water, seven times the chloride concentration, about six times the sodium and one-half the potassium concentration of the adult muscle. Their findings were in agreement with those reported by previous investigators on other species in that sodium and chloride concentration decreased and potassium concentration increased during the development of the animal. Since the animal body is a non-homogenous system, differences between various organs and tissues of the body are expected during development and growth. Dickerson (1960) found that the body weight of the chick was almost doubled during the first 2½ weeks after hatching, while there was a tenfold increase in the weight of the pectoral muscle during the same time. The sartorius muscle grew at a slower rate than the pectoral and was always lighter. Water, chloride, sodium and

extracellular protein-nitrogen/kg wet weight decreased while potassium, phosphorus and magnesium increased in the pectoral muscle of the chick during the first 2½ weeks after hatching. Table 1 gives the results obtained by Dickerson (1960).

Table 1

The effect of growth on the body weight and on the weight of the pectoral and sartorius muscles

	Average weights (g) per bird are given			
Age, weeks	0	2½	4	27
Body weight	52.4	93	195	3365
Pectoral muscle	0.39	4.12	12.1	326
Sartorius muscle	0.13	0.28	0.53	13.5

Dickerson (1960)

Dickerson (1962) gave an analysis of the effect of development and growth on the composition of bones of the pig, rat and fowl. He found that in the fresh bones of pig and fowl there was a large rise in the percentage of fat and a decrease in the proportion of water after 20 to 45 days of age in the pig, and 4 weeks of age in the fowl. His analysis included the humerus and femur of the pig, the femur of the rat and the femur of the fowl. The proportion of fat was generally small in all of the three species mentioned above during the early stage of growth. The author pointed out that the fall in the percentage of water on the fat-free basis was due to the deposition of minerals.

The rise in the proportion of total nitrogen accounted for a very small role in the decrease of water. The proportion of collagen accounted for the percentage of total nitrogen which was increased in all the species. On the fat-free basis, there was an increase of calcium and phosphorus in the femur of the fowl during growth. At hatching the calcium was 2.9 g/100 g fat-free fresh bones, increasing in the adult stage to 12.8 g/100 g fat-free fresh bones. Phosphorus was 1.41 g/100 g fat-free bones at hatching and increased to 5.56 g/100 g fat-free bones at the adult stage. The ratio Ca/N was also increased during growth: this was 1.37 at hatching and rose to 3.78 at late life.

The variation in the chemical composition of the animal body during growth and development may be affected by fat and fatty tissues, extracellular fluid, bone and its degree of calcification. Variation also can be caused by a haemorrhage or bleeding the animal during dissection and preparation. Widdowson and Southgate (1959) reported a loss of chloride of the skeletal muscle of pigs which had been bled compared with those which had not been bled:

13 m.equiv. of Cl/kg fresh muscle was obtained in the bled pigs.

22 m.equiv. of Cl/kg fresh muscle was obtained in the non-bled pigs.

The same authors stated that severe bleeding in man, fowl and pig before death causes a considerable fall in the

concentration of chloride and sodium of the skeletal muscle but little change in the proportion of water, potassium and phosphorus. Dickerson and Widdowson (1960) showed that the concentration of sodium and chloride of the thigh muscle of human adults was affected by the degree of bleeding.

23.0 m.equiv. of Na/kg fresh muscle was found in severely bled adults.

30.0 m.equiv. of Na/kg fresh muscle was found in slightly bled adults.

17.3 m.equiv. of Cl/kg fresh muscle was found in severely bled adults.

22.1 m.equiv. of Cl/kg fresh muscle was found in slightly bled adults.

In the work carried out by Dickerson (1960) on the thigh muscles of humans and pigs during development before and after birth, cellular nitrogen, potassium and phosphorus concentrations increased while extracellular ions Na and Cl decreased during development. There was also a decrease in the concentration of calcium.

The effect of growth on the chemical composition of the body has been studied by Vernadakis and Woodbury (1964) in an experiment on rats. Their results were similar to those obtained by Barlow and Manery (1954). The Vernadakis and Woodbury results showed that muscle water content during maturation was accompanied by a rise in total nitrogen and not in fat concentration. The results also revealed

that most of the total muscle nitrogen was protein nitrogen, therefore, the authors assumed that water was replaced by protein during development. They favoured the idea that the increase in total muscle nitrogen concentration, which is almost protein, implied either an increase in the number of muscle fibres or in cell volume. The increase in cell mass was supported by the distribution of potassium in the body where the intracellular concentration of potassium remained constant, irrespective of the increase in total potassium concentration during development. The changes in potassium concentration which took place during maturation were associated with a relative decrease in extracellular fluid and an increase in the cell mass. In earlier results, Vernadakis and Woodbury (1962) found that during the growth of the rat, total brain water content and total Na and Cl concentrations progressively decreased, whereas that of K increased. Avian skeletal muscles of growing chicks have been investigated by Draper (1968). Breast and thigh muscles of the chick from hatching to 70 days of age have been analysed. Sodium was found to be significantly higher than potassium in both muscles during the first week after hatching. The situation was then reversed and potassium became the dominant ion. The rise in potassium content during development was associated with a rise in protein content. It had also been reported by the same author that the thigh muscle of chickens have a different

composition from the breast muscle throughout life. At first, thigh muscles have more protein, fat and potassium than the breast muscles: in about 7-14 days the situation is changed and breast muscle becomes high in protein and potassium and low in sodium and fat. Table 2 gives the results obtained by Draper (1968).

Table 2

Analysis of breast and leg muscles in growing chickens. Solids, protein (N x 6.25) and fat are expressed in g/kg wet weight. Na and K are expressed in mM/kg wet weight. Results from days 0.2 and 3 are from pooled samples from six birds; day 7 is from six birds analysed in pairs (± SEM); days 17 and 70 are the means of six individual analyses (± SEM)

	Age (days)					
	0	2	3	7	17	70
Live weight (g)	41	41	45	73 ± 6.3	188 ± 4.6	1342 ± 37
Breast muscle solids	152	147	151	230 ± 3.7	257 ± 2.5	273 ± 6.0
" " protein	92	105	116	189 ± 2.0	201 ± 1.8	234 ± 3.7
" " fat	44	31	45	13 ± 0.3	14 ± 0.7	12 ± 1.0
" " Na	81	101	63	46 ± 3.5	45 ± 2.6	36 ± 1.4
" " K	36	62	54	108 ± 4.3	113 ± 2.7	115 ± 1.7
Thigh muscle solids	241	274	236	284 ± 5.4	274 ± 7.5	254 ± 11
" " protein	120	159	134	173 ± 1.2	162 ± 2.4	192 ± 4.9
" " fat	94	100	83	99 ± 8.9	80 ± 5.4	48 ± 2.3
" " Na	66	89	65	62 ± 3.3	60 ± 3.3	45 ± 1.5
" " K	47	90	69	99 ± 4.2	105 ± 2.6	103 ± 3.9

DRAPER (1968)

Histological studies of human skeletal muscle have been carried out by Widdowson and Dickerson (1964). Sections of muscles from a 20-week old human foetus, a full-term baby and an adult man have been studied. In the muscle of the 20-week old foetus, the fibres were small, relatively few in number and widely separated by

extracellular material; the nuclei occupied a larger proportion of the cell than they did at a later stage. At term, the authors found that the fibres were still small but they were greater in number and they were more closely packed together. In the adult muscle, the fibres were much larger in diameter, the nuclei were comparatively small and there was little space between the fibres. The authors came to the conclusion that the decrease in the proportion of extracellular fluid in human skeletal muscle during development was to be accounted for during early prenatal growth by the increase in the number of muscle fibres, and during later growth by the increase in size of the existing fibres. Widdowson (1969) stated that the changes in the chemical composition of the skeletal muscle occurred as a result of changes in the histological structure of the muscle. As a result of growth and development the percentage of water falls. This fall is accompanied by a fall in the amounts of chloride and sodium and an increase in the amount of potassium per unit weight. The author also pointed out that the concentration of nitrogen in the human muscle is rising with development and the proportion of the total nitrogen contributed by the extracellular protein nitrogen increases to a maximum at about the time of birth and falls to a lower level in the adult stage. The proportion of extracellular protein increases whilst the cells are increasing in number and decreases whilst they are increasing in size. The changes in the chemical

anatomy of the animal body including man, are not confined to growth and development only; disease and nutritional disorders can alter the chemical composition of the body and its components. Starvation or undernutrition for a considerable period of time leads to a loss in weight of the animal body. Other changes have been reported by Dicker (1949) who found an increase in the proportion of water in the muscle of adult rats which were starved for 6 days. Chloride and sodium per unit of muscle weight also increased during starvation. Fourman and McConkey (1958) and McConkey (1959) agreed that the proportion of extracellular fluid in the undernourished human subject was increased. The fat cells and the muscle cells shrunk but their number remained unchanged. They pointed out that the proportional increase in the extracellular fluid was a necessity if the shrunken muscle cells were to retain a surrounding film of their interstitial fluid: disturbance in the chemical composition of the body during undernutrition had been reported by Elkinton and Widdowson (1959). They found that fat, potassium and potassium/nitrogen ratio had been diminished. Extracellular water and chloride were increased when the rat was kept undernourished for 7 to 13 weeks. Widdowson and Dickerson (1964) stated that the increase in the proportion of fluid outside the cells during starvation was always greater than the increase in the proportion of total water in the muscle, because, as the cell mass was reduced there was a

fall in the amount of fluid in the cells. The cockerel's femur had been analysed by Dickerson and McCance (1961) when the bird was undernourished during early age (2½ weeks). There was an increase in the percentages of calcium and phosphorus of the cockerel's femur. In the adult bird (27 weeks) there was an increase in the percentage of water and a decrease in the percentage of fat in the femur. Total nitrogen, collagen, calcium and phosphorus had been decreased on the fat-free basis during undernutrition.

It has been reported by Guthrie and Brown (1968) that when rats were subjected to severe undernutrition ~~for~~ from 2 days following birth until they were between 3 and 9 weeks of age, and subsequently fed an adequate diet until becoming 19 weeks of age, body weight and organ weight (liver, kidneys, heart and brain) of all deprived groups were significantly lower than those which had been adequately fed from birth until adult age of 19 weeks. They stated that body weights of all deprived groups were depressed to a greater extent than ~~all organs.~~ in any of the four organs. They also indicated that, if growth is retarded in the rat during the first three weeks of age, little further retardation occurs if the period of undernutrition is increased to an additional four weeks. Undernutrition beyond seven weeks leads to a greater retardation in growth and reduces the response to refeeding. The retardation of growth as a result of severe undernutrition during early life has been explained by Winick and Noble (1966) and by Widdowson (1970).

They pointed out that if undernutrition occurs during cell division, then permanent retardation will result, but if the effect of undernutrition takes place after the number of cells is fixed, the animal will be able to recover more easily. The chemical composition of the body can also be affected by the composition of the diet. Yoshida and Hoshii (1972) stated that a decrease in dietary energy levels from 73% to 60% was effective to decrease abdominal fat content of both laying hens and growing chicks. The increase in dietary protein levels from 16% to 28% was effective to decrease abdominal fat of growing chicks only. Dietary protein level had little effect on the abdominal fat of laying hens. This was related to the difference in protein or fat metabolism between laying hens and growing chicks. It has also been reported by Hijikuro and Morimoto (1972) that the sexual maturity of the White Leghorn growing fowl (10 to 20 weeks of age) had been delayed by about 10 days when a low energy diet was fed.

Temperature has also been found to affect the growth of the animal body. Osbaldiston (1966) found that the growth rate and the growth response in the domestic chicken had been affected by temperature. The growth rate of chicks kept at 7.2^{o}C was significantly inferior to those kept at 32^{o}C. The effect of low temperature (12^{o}C) on the growth rate was higher during the first 2 to 3 weeks after hatching

than later in life, and the body size, rather than the climate, became the most important factor in determining the succeeding weight gain. The decrease in body weight which occurred when the chick was placed under low temperature could be related to the increase in the energy output in terms of heat production by the bird. Freeman (1966) pointed out that when the domestic fowl was kept below the lower critical temperature (14.5°C) it became more active. As the environmental temperature falls, body heat production rises until it reaches its maximum. If environmental temperature falls further heat loss can no longer be balanced by heat production, body temperature decreases, metabolic intensity declines and death, due to hypothermia occurs (King and Farner, 1961). Smith and Oliver (1971) found that the heat production of the White Leghorn fed a maintenance ration decreased from 99.2 to 89.2 Kcal/kg/day when the environmental temperature was raised from 22°C to 29°C. Hoffman and Shaffner (1950) observed that the basal metabolic rate of 11-week old chicks reared at a temperature of 26.5°C from 7 weeks of age was less than that of chicks reared at a temperature of 7.2°C. This change was associated with changes in size of the thyroid gland and the rate of thyroid secretion.

Jones and Huston (1967) studied the effects of environmental temperature upon domestic fowls deprived of feed and water. They found that age played an important

part in producing these effects. The young fowl (2 to 4 weeks of age) when deprived of water, lost weight very rapidly and was dead within 10 to 14 days, while the adult bird (one year old) lived from 30 to 98 days. The reason for this given by the authors was that adult birds have more advantages than young birds in that they have a relatively smaller surface area for evaporation, a lower body content, a lower water requirement rate and a lower excretion rate. Large reservoirs of body fat in adult birds also became a source of metabolic water and energy which is not available in the young bird. The data presented by these authors showed that regardless of the age of the birds, sex or breed, death will occur due to water deprivation when approximately 45% of the normal body weight has been lost. The domestic fowl deprived of water survived longer in a lower, rather than in a higher, environmental temperature. In the high environmental temperature more water is required to maintain body temperature and when this is not available the animal dies of heat prostration rather than desiccation. In the cold environment (8^{o}C) feed rather than water seemed to be the limiting factor for survival. The birds that survived the longest had less body fat, suggesting that they depleted their energy supply (Jones and Huston, 1967).

Babinski and Onanoff (1888), quoted by Widdowson and Dickerson (1964) stated that "all the muscles in the body

of an animal probably undergo some degree of atrophy during undernutrition, but the order in which the individual muscles develop and the extent to which they are used probably accounts for the fact that some muscles atrophy more than others". The order in which the tissues of the body may atrophy as a result of undernutrition or disease or other factors may depend upon their function and the stage of development the animal has reached when the effect occurs.

It has been stated by McMeekan (1940) that parts of the body which are essential for the existence of the animal and to body function develop relatively well at birth and grow at a slower rate than the body as a whole, while the organs primarily associated with movement and storage reserves, develop relatively slowly at birth but grow faster during post-natal life. Widdowson, Dickerson and McCance (1960) gave an account of the way in which the organs and tissues of the body were affected. They stated that, when the animal was subjected to undernutrition, some processes tended to be reversed more easily than others and some organs tended to be more affected than others depending upon the degree of development that had been reached at the time of the effect. They also pointed out that the organs which function and undergo most of their chemical development during foetal life, and whose continued function during post-natal life is vital to the existence of the animal, e.g. heart, kidneys and liver, were the ones they found to

change least in chemical composition as a result of undernutrition. Skeletal muscle, on the other hand, was found to undergo substantial changes in chemical composition after birth when the animal was undernourished. Dickerson and McCance (1960) carried out an experiment on the effect of undernutrition on the avian skeletal muscle. They found that in the birds which had been undernourished for 25 weeks from 2½ weeks of age, the pectoral and sartorius muscles gained about the same proportion of their initial weight which means that the growth of the pectoral muscle was affected more than the sartorius muscle. The effect was more severe in the birds which were undernourished from 27 to 42 weeks of age where the pectoral muscle of these birds was grossly atrophied and lost 90% of its initial weight, whereas the sartorius muscle sustained only 50% loss. The authors found that the chemical composition of the pectoral muscle was altered. The extracellular ions, chloride and sodium, the total extracellular protein nitrogen and collagen were increased per unit weight. There was a small rise in the amount of water and a fall in the total nitrogen. The intracellular protein was reduced more than the total nitrogen. The fall in the amount of intracellular protein was accompanied by a fall in the intracellular ions, potassium and phosphorus. The authors also explained that changes occurred in the skeletal muscle of the young birds and the old ones during undernutrition. In the young chicks the changes were caused by the greater

retardation of cell growth relative to that of the connective tissues, while in the older birds, the changes were caused by the greater atrophy of the cells relative to the connective tissues. Hogan and Scow (1957) found that in the thigh muscle of a fasting rat only two fractions (myosin and sarcoplasmic protein) were reduced. The stroma and non-protein nitrogen fractions were not affected. The authors also pointed out that only 20% to 27% of the calories that came from the thigh muscle during fasting were derived from protein and the rest from fat. The relative loss of fat was greater and took place earlier than that of the protein fraction.

3. MATERIALS AND METHODS

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Broiler and layer type hens were used. The layer type hens were Thornber 909 (brown egg) and Thornber 808 (white egg). ~~and were designed to be~~ They were killed at the following ages: 4, 6, 8, 12, 16, 18, 19, 20, 21, 22, 23, 24, 26, 28, 30 and 76 weeks. Thornber 909 birds - a heavy hybrid - were employed to study the Anatomical aspects and Thornber 808 birds - a light hybrid - were used to study the Chemical aspects. All birds were maintained at the Outstation of the Poultry Research Centre in Roslin Village. One hundred and ninety-two birds were involved in this experiment: half were Thornber 909 and the other half Thornber 808. A group of six birds of the same age were killed at each time in both breeds. All birds were killed by a lethal dose of Nembutal (60 g Pentobarbitone sodium/ml plus alcohol 10% v.v., and propylene glycol 20% v.v. B.Vet.C. manufactured by Abbott Laboratories) intravenously injected into the wing.

3.1. Anatomical aspects

In this section of the experiment, the birds were weighed then killed by an overdose of Nembutal. Dissection was carried out immediately after death. Nine organs were dissected from these birds, namely, heart, liver, kidneys, adrenal, spleen, ovary, oviduct, gizzard and gut. The container for each organ was carefully weighed and the dissected organ placed in it. The total weight was then

recorded. The dissected organs of the body were placed with their container in an oven (100°C) until a constant weight was reached. Dry matter and water contents were then estimated. No further chemical analysis was done on these organs except the liver which was kept for further chemical determination.

3.2. Chemical aspects

In this section muscle tissue is considered separately from the body carcass in order to facilitate considerations of chemical anatomy. Firstly, the feathers were removed and the crop and gizzard contents expelled. Then each carcass was divided into the breast and thigh muscles and the body carcass, after the breast and thigh muscles had been dissected and kept separately. According to George and Berger (1966) the breast muscle, in biochemical studies, should not be referred to collectively because it is composed of two different muscles: the pectoralis and the supracoracoideus which are distinctly, but not profoundly, different in cellular organisation and biochemical properties. As the leg muscles are so different in this study the whole breast muscle mass was accepted, i.e. the pectoralis (major and minor) and the supracoracoideus muscles. The thigh muscle mass used included all muscles associated with the femur. The birds used in this section of the experiment were Thornber 808. After the live weight of each bird had been recorded a lethal injection of Nembutal was given

into the wing. The birds were completely plucked by hand and the dissection was carried out immediately. The breast muscle of both sides was completely dissected, freed from visible fat and tendon and placed in a plastic container which had already been weighed: the total weight was then recorded. The muscle sample was put into a deep freeze (-20°C) and kept until it was required for chemical analysis. The thigh muscle was also dissected from both sides of the bird and dealt with in the same way as that described for the breast muscle. After the gizzard and cloacal contents had been expelled the rest of the body carcass was weighed and placed in a polythene bag which was sealed and put in a deep freeze until required for further analysis.

3.2.1. Chemical analysis of the skeletal muscle

Total solids

The muscle sample was taken out of the deep freeze and allowed to thaw. It was then carefully cut into small pieces with fine scissors and run through a manual mincer twice. The minced material was transferred from the mincer to a container and duplicate aliquots were taken for water determination. This was obtained by drying the muscle sample in an oven (100°C) until a constant weight was achieved.

Total lipids

The dried muscle sample was very finely ground using

a coffee grinder. The ground material was then kept in a small polythene bag which was sealed and stored in a desiccator. Aliquots of 2.0 g of the muscle material were prepared in duplicates and wrapped in filter paper. A blank test was carried out on the filter paper for fat content. The results of the test showed that the filter paper used in this work contained no fat. Fat determination was carried out by the Soxhlet Continuous Extraction Apparatus. Chloroform was used as a fat extractor. The time found to be satisfactory for the extraction was about seven hours. The Soxhlet Method was preferred to the method described by Bligh and Dyer (1959) because of the further use of the same sample, after the fat had been estimated, for the total nitrogen determination.

Total nitrogen

This was performed on the apparatus of the "Gallenkamp" Universal Kjeldahl. The principle of the Kjeldahl Method is based on the conversion of all the nitrogen present in the tissue sample into ammonia by the use of catalysts and hot concentrated sulphuric acid. After the muscle sample was used for fat determination the sample, still wrapped in filter paper, was dropped down the neck of a clean, dry 500 ml Kjeldahl flask. This procedure enabled one to get the sample into the flask without any loss by sticking to the neck. 9.5 g of anhydrous sodium sulphate, 0.5 g copper

sulphate and 25 ml of concentrated sulphuric acid were added to the flask which was then placed on the digestion part of the apparatus and allowed to heat, gently at first until foaming ceased, and then more strongly. The digestion took about 2½ hours. The flask and the contents were then allowed to cool before the distillation part was begun. Meanwhile 25 ml of 1N hydrochloric acid was measured by means of pipette into a 500 ml conical flask and about 20 drops of indicator solution (Indicator "4460" produced by B.D.H. Ltd) was added. The flask with the contents was placed under the condenser on the distillation part of the Kjeldahl equipment and the condenser delivery tube was dipped below the surface of the acid in the flask. A small piece of granulated zinc was added to the flask to act as an anti-bumping agent. Forty per cent sodium hydroxide was carefully added until the contents of the flask became alkaline. This was predicted by the dark blue colour of the liquid in the flask. The blue colour is due to the formation of cuprammonium ion. The flask was then immediately connected to the splash head and the condenser of the distillation part of the apparatus and left to be distilled. This took about 1½ hours. The conical flask with the contents was then lifted from the condenser and titrated with a standard 1N sodium hydroxide by means of burette until the colour changed from pink to green. A blank test was carried out exactly as described for the actual test but without the muscle sample.

Calculation

Nitrogen content of the muscle sample (%) =

$$\frac{(B-v) \times 0.014 \times 100}{W}$$ where:-

V = volume in mls of 1N sodium hydroxide solution used to titrate the distillate in the actual test.

B = volume in mls of 1N sodium hydroxide solution used to titrate the distillate in the blank test.

W = weight in grams of the muscle sample taken for the estimation.

0.014 = amount of N in grams ~~in~~ (equivalent to) 1 ml of N/1 HCl.

Protein content of the sample (%) = Nitrogen content (%) X 6.25.

Mineral contents

The mineral composition of the skeletal muscle was estimated by two means: (1) atomic absorption spectroscopy (AAS) (Willis, 1965) and (2) X-ray fluorescence spectrometry (XRF) (Jenkins and De Vries, 1967). In the preparation of the sample for AAS analysis the sample was finely ground, placed in a platinum crucible and ashed in a muffle furnace at 500°C for approximately 18 hours. The ashed residual was then dissolved in a small quantity of distilled water to which a drop of 1N HCl had been added, then transferred to a volumetric flask and made up to volume. After suitable dilution was prepared, potassium, sodium, calcium and magnesium were determined. The AAS method was usually

used in two cases: (1) when the size of the aliquot was small (less than 2.0 g) and (2) when potassium, sodium, calcium and magnesium were likely to be determined. The model, Techtron AA100 was used in this analysis.

In the second method, where the XRF technique was used, the sample was large in size (more than 4.0 g) and, in addition to the four elements estimated by the AAS technique, more minerals had been determined. The XRF technique was used in this research for the first time for determining mineral composition of a biological material from animals. The results obtained were satisfactory. The principle of this technique is based on X-ray fluorescence where the primary X-ray, which comes from the tube inside the machine, is used to bombard the specimen and produce secondary radiation. This secondary radiation is characteristic for each element in the specimen. The radiation from the sample is passed through the primary collimator which selects a parallel beam and directs it onto the analysing crystal where it is diffracted according to its wavelength. The radiation of a selected wavelength finally hits the collector (a gas flow proportional counter or a scintillation counter) where the X-ray photons are converted to voltage pulses which are then amplified and passed to the scaler circuits. The theory of this technique is illustrated in a diagram presented on the following page.

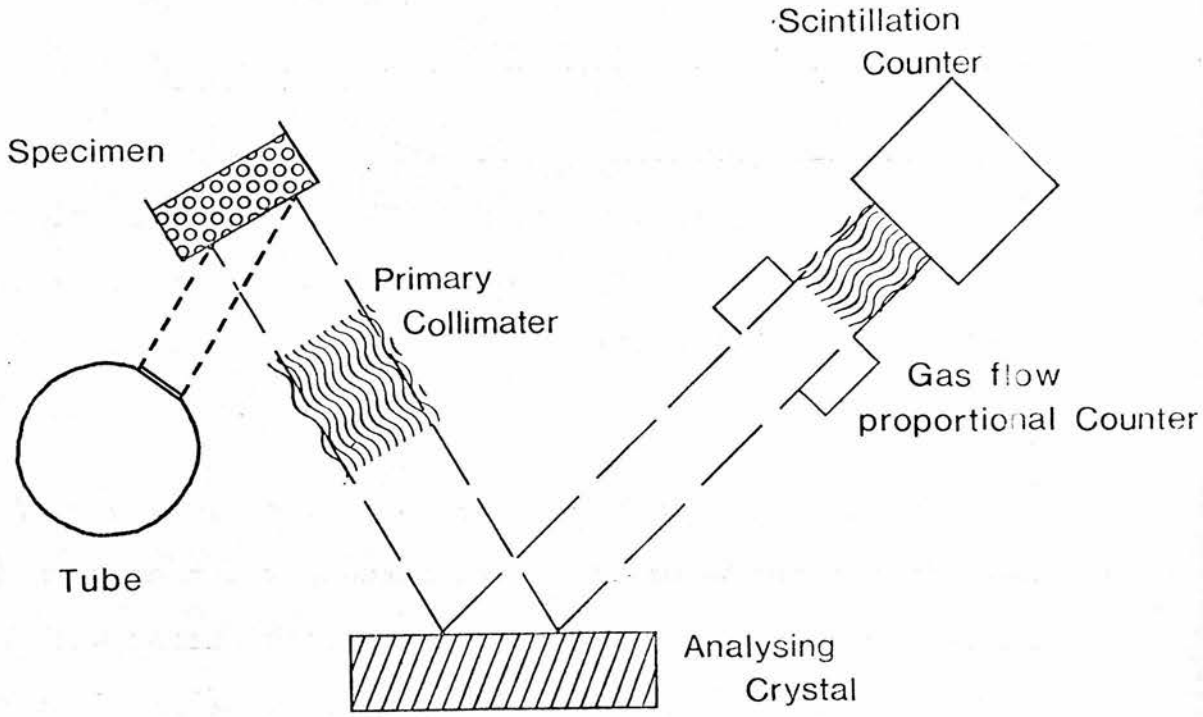

Illustration of the XRF technique for mineral estimation.

(JENKINS and DE VRIES,1967)

In all examples of the different tissues some hundreds of samples were analysed by both XRF and AAS methods. No significant difference was found between the two methods. The accuracy of both methods was better than 5% and in many better than 3%.

3.2.2. Chemical analysis of the body carcass

The body carcass, as has been mentioned before, is the part of the body remaining after the breast and thigh muscles have been removed. The preparation of the carcass of the bird for chemical analysis was carried out as follows:

Total solids

The frozen carcass of each bird was taken out of the deep freeze and weighed. The carcass was then sawn into small pieces using a power band saw meat cutter with special blade clearing guards to prevent loss of material by saw action (Biro, Marblehead, Ohio). The small pieces of carcass were collected and weighed. The loss during this stage was less than 2%. The small pieces of carcass were then run through an electric mincer of 1½ h.p. (Biro, Marblehead, Ohio). The carcass was minced three times using a coarse die and then twice using a fine die. The minced material was thoroughly mixed and the samples were taken in duplicates. The aluminium trays which were used as sample containers were previously weighed. The container with the sample was stored in a deep freeze (-20^{o}C).

The frozen sample was taken to a freeze drier and kept for about 72 hours until it was completely dried. Water content was then estimated from the difference between wet weight and the dry weight of the sample.

Total lipids

The dried sample of the carcass was broken into small pieces and put into a coffee grinder. Because of the high fat content of the carcass it was not convenient to obtain a finely ground material. The material was rather soft and sticky, therefore a large size of aliquot was taken in duplicate for the fat and nitrogen determinations. The difference between the duplicates was not more than 1%. Soxhlet Continuous Apparatus was used for fat estimation and chloroform was used in the extraction which lasted about 7 hours. The procedure of preparing the sample for fat extraction was similar to that described for the skeletal muscle.

Total nitrogen

After the fat had been estimated the sample was taken for total nitrogen determination. The nitrogen extraction was carried out by the use of Standard Kjeldahl Apparatus made by "Gallenkamp". The factor 6.25 was used to convert the total nitrogen in the sample to total protein. Since most of the nitrogen in these samples had come from the protein, no effort was made to assess the non-protein nitrogen. The estimation of the total nitrogen in the

carcass tissue was carried out in the same way as that described for the skeletal muscle.

Mineral content

Because of the high fat content of the body carcass, it was not suitable to obtain a finely ground material which could be pelleted under a pressure of about 10 tons/in^2 for the XRF analysis. The sample was diluted with cellulose and urea to give the texture some support when the sample was pressed. This was not successful and the sample still fell apart when it was compressed. Fat was extracted from the carcass tissue with petroleum spirit (b.pt 40^o-60^{o}C) and the sample was then re-ground. The extraction of fat from the sample with petroleum spirit had not affected the mineral content of the carcass sample. The ground material of the carcass produced after extraction was convenient for making the firm pellets suitable for XRF analysis. This technique was also used in preparing pellets from muscle samples.

3.3. Low temperature effects on growing chickens

Broiler type birds were used to study the effect of a period of reduced temperature (10^{o}C) on the body cell mass. They were also used to investigate the way in which certain muscles are affected more than others when the animal suffers any particular discomfort such as mild chilling. One hundred and eight chicks were used in this experiment. All chicks were weighed at one-day old and

were killed in batches at 1, 2, 5, 9 and 14 days of age. They were divided into two main groups, the Control group and the Experimental group. The number of birds killed in each group at each age was 12. The experimental group was taken into a cold environment which was a large room maintained at a temperature of 10°C. They were kept there for 4 hours and were prevented from huddling together by placing them singly or in pairs in compartmented wire cages. All the experimental birds were cooled when they were newly hatched (i.e. approximately one-day old). The experimental group and the control group were kept separate in a heated compartment where food and water were constantly available. At the first day of age 12 chicks of the control group were killed. Breast and thigh muscles of one side only were completely dissected and placed in a plastic container, which had already been weighed, and the total weight was noted. The muscle sample was then put into the deep freeze (-20°C) and kept until it was required for chemical analysis. The yolk sac had been removed and the rest of the body carcass was weighed and put into a polythene bag which was sealed and kept in the deep freeze. Water and dry matter of the breast and thigh muscles were determined by weighing the sample before and after approximately 16 hours drying at 100°C. Because the size of the individual muscle samples was so small (0.043-1.460 g dry weight) further chemical analysis of each individual muscle, particularly by the XRF technique,

was impossible. Therefore, the breast and thigh muscles of each 12 birds from each age were separately mixed and made up to two separate samples. The dried muscle sample was finely ground and prepared for chemical analysis. Aliquots were taken in duplicates and fat, protein (N X 6.25) and minerals (Na, K, Mg and Ca) were determined. Fat was estimated by ~~Soxhelt~~ Soxhlet Extraction with chloroform, protein was determined by Kjeldahl Method and minerals were determined by Atomic Absorption Spectroscopy. The techniques used in these determinations were similar to those described for the chemical aspects. The carcass body of each 12 birds of one age were also minced together using an electric mincer of 1½ h.p. (Biro, Marblehead, Ohio) and the minced material was thoroughly mixed. Samples were taken in duplicates for water, fat, protein and mineral determinations. Fat and protein were determined by ~~Soxhelt~~ Soxhlet and Kjeldahl methods respectively. Minerals were determined by the XRF technique. The technical procedures were similar to those described earlier in the chapter.

4. RESULTS

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4.1. The Anatomical Aspects

In this part of the thesis the bird has been looked at from the point of view of the internal organs and the way they grow. The nine internal organs studied were the heart, the liver, the kidneys, the spleen, the adrenal, the ovary, the oviduct, the gizzard and the gut. Before examining the growth of these organs individually, it is quite interesting to consider the growth of the bird before and after removal of these organs. Fig. 1 gives the live body weight before and after the nine organs had been dissected and the changes which occur with aging in layer type hens (Thornber 909).

The domestic fowl (Gallus domesticus) is a peculiar animal in that its true life cycle is possibly about 12 years, but in modern agricultural practice a bird of 1.5 years is considered to be an 'old' bird. In the studies presented in this work the agricultural practical term for the young and old bird is used. Table 3 gives the weight of the organs mentioned above as a percentage of the body weight of the young and old fowl. The proportion of heart, liver, kidneys, spleen and gut given in Table 3 were found to be similar to those of the human body reported by Widdowson et al (1951) and Passmore and Draper (1970). The growth curve of the live weight as it appears in Fig. 1 shows a rapid increase in early life, that is

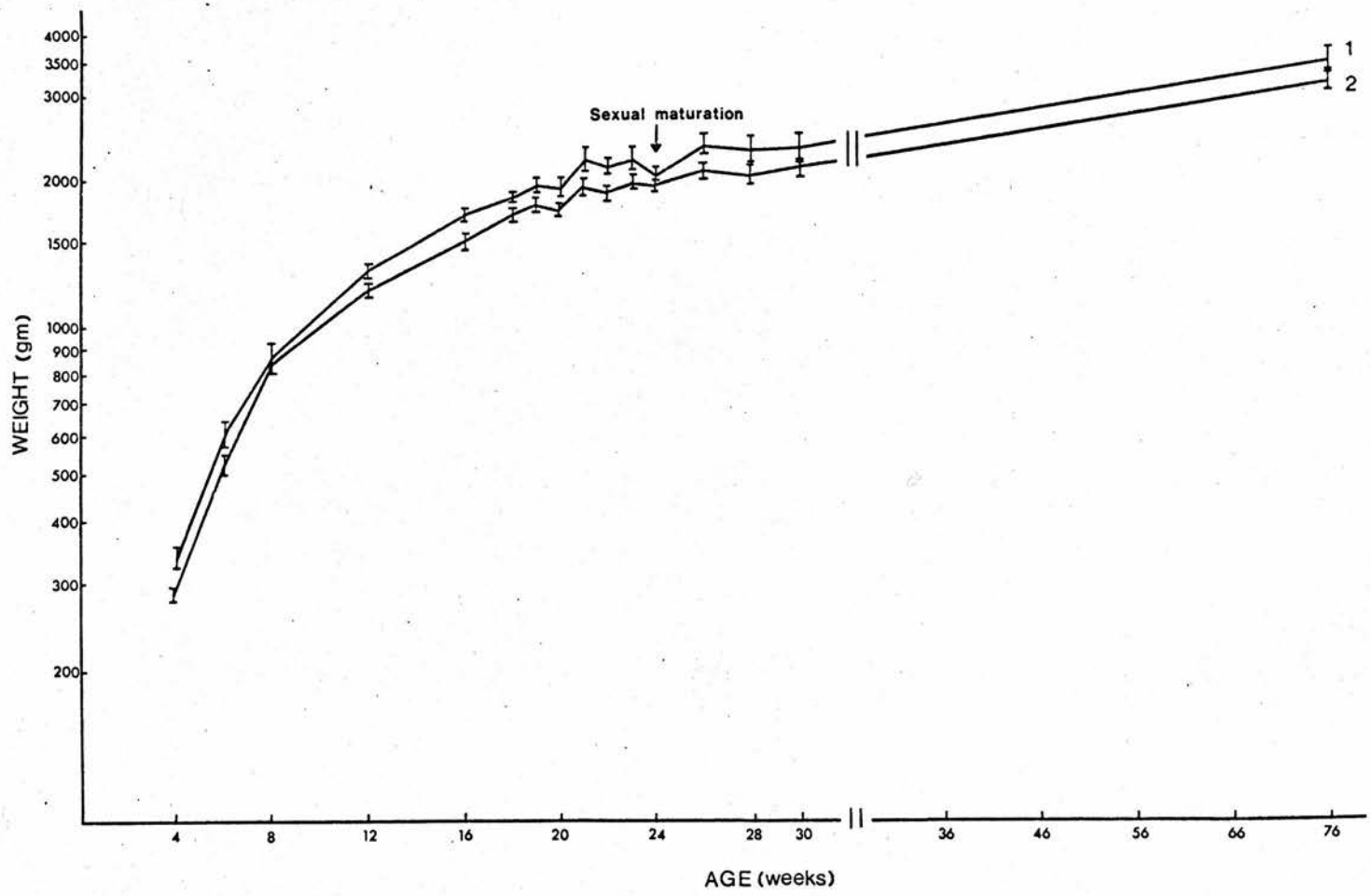

FIG. 1 Live weight and eviscerated weight in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂.

1. Live weight. 2. Eviscerated weight.

TABLE 3

Weights of organs as a percentage of body weight in the young and old fowl

Values are mean of six birds (± SEM)

		Young fowl Age: 4 weeks	Old fowl Age: 1.5 years
Body weight	(g)	340 ± 11.92	3510 ± 59.65
Heart	(%)	0.64 ± 0.06	0.30 ± 0.02
Liver	(%)	3.24 ± 0.12	2.54 ± 0.14
Kidneys	(%)	1.23 ± 0.08	0.50 ± 0.03
Spleen	(%)	0.18 ± 0.05	0.13 ± 0.00
Adrenals	(%)	0.01 ± 0.00	0.05 ± 0.00
Ovary	(%)	0.03 ± 0.00	0.28 ± 0.02
Oviduct	(%)	0.01 ± 0.00	1.71 ± 0.46
Gizzard	(%)	2.72 ± 0.16	0.86 ± 0.06
Gut	(%)	7.35 ± 0.59	4.00 ± 0.29

for the first 8 weeks of age, thereafter the rate of increase per unit of time is greatly reduced but it would seem to be far from zero at 76 weeks. Equations of the Gomperts type (Laird et al, 1965 and Laird, 1966) could be applied to these results but, as will be seen (e.g. Fig. 16) the use of such equations would not be particularly helpful. The important point in this work is not the growth as such but the components of this growth. One of these components, strictly speaking, is not growth but accumulations of relatively inert matter (Brody, 1945) that is the fat mass. The growth curve of an animal as shown in Fig. 1 is an integration of a complex of interacting processes. One of the purposes of this study is to consider how one may obtain information about these growth elements.

There are four major morphological components making up the body weight of the animal. These are, cell mass, skeletal mass, extracellular water content and fat mass. As will become apparent in these particular animals, the fat content gives a false impression of the growth situation especially in the early stages of sexual maturity. In another section in this thesis, 'The Chemical Aspects', a clear picture is presented (Fig. 16) of exactly what makes up the body weight at each stage of maturation. Here one can see clearly how fat rather than protein accumulation is the important factor in the increasing body weight in the later stages. The most important practical component in

a carcass in the agricultural context is the muscle mass or the meat yield which is mainly protein. This factor is not ascertainable with any precision from the growth curve, particularly in the modern hybrid, high intensity laying hen which tends to be obese, to use a mammalian term.

Fig. 2 gives the wet weight and dry weight of the heart of the domestic fowl. The size of the heart varies between individual birds and between different ages. The heart weighs about 2 g at 4 weeks of age, then increases in weight up to about 10 g when the bird reaches 76 weeks of age. It comprises about 0.64% to 0.30% of the body weight in the young and old fowl respectively. The heart of the domestic fowl, as shown in Fig. 2, increases in weight during early life when cell growth is maximal and hence oxygen demand is steadily increasing. Presumably after 20 weeks of age the increase in new cells declines and the growth increase is predominantly in the relatively inert obese tissue, thus there is no need for an ever increasing heart size, particularly in animals with limited exercise possibilities.

Fig. 3 shows the weight of the liver and its protein and fat contents during different ages of the layer type hen. The liver is the largest metabolic organ of the body and its weight varies considerably between birds at different ages. At 4 weeks of age the liver weighs about 12 g and

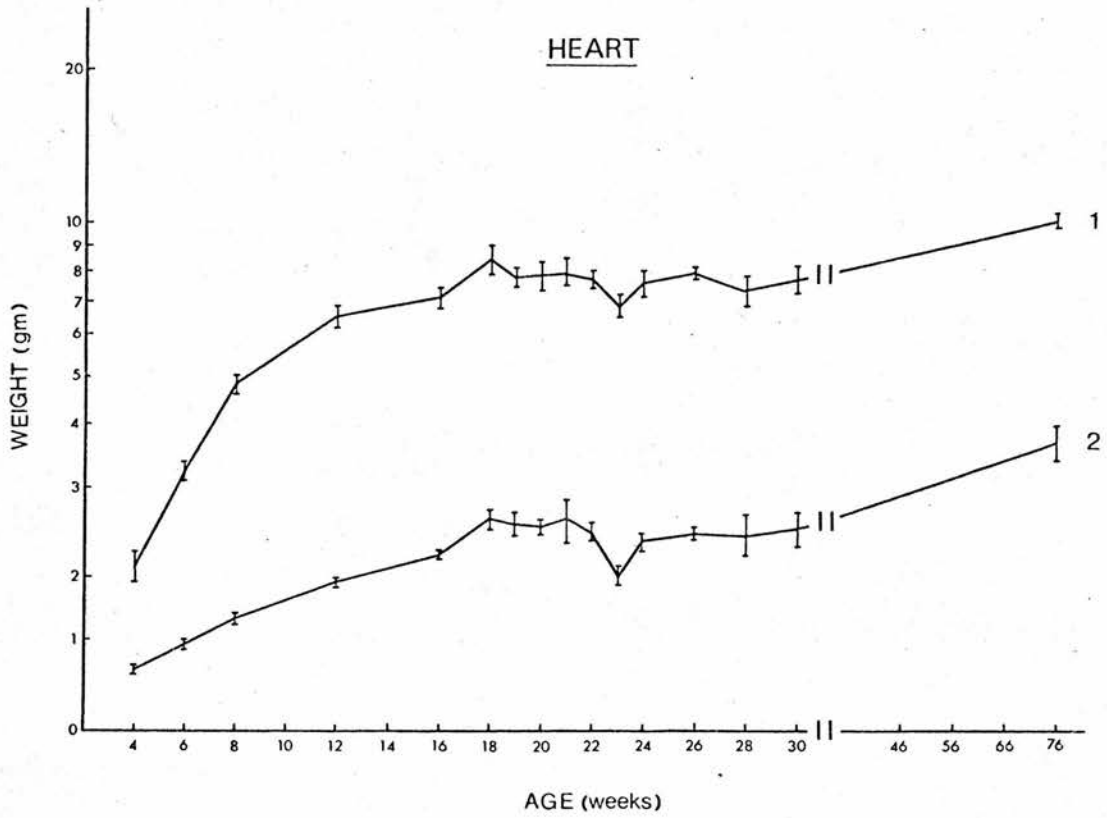

FIG. 2 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♀♀. 1. Wet weight. 2. Dry weight.

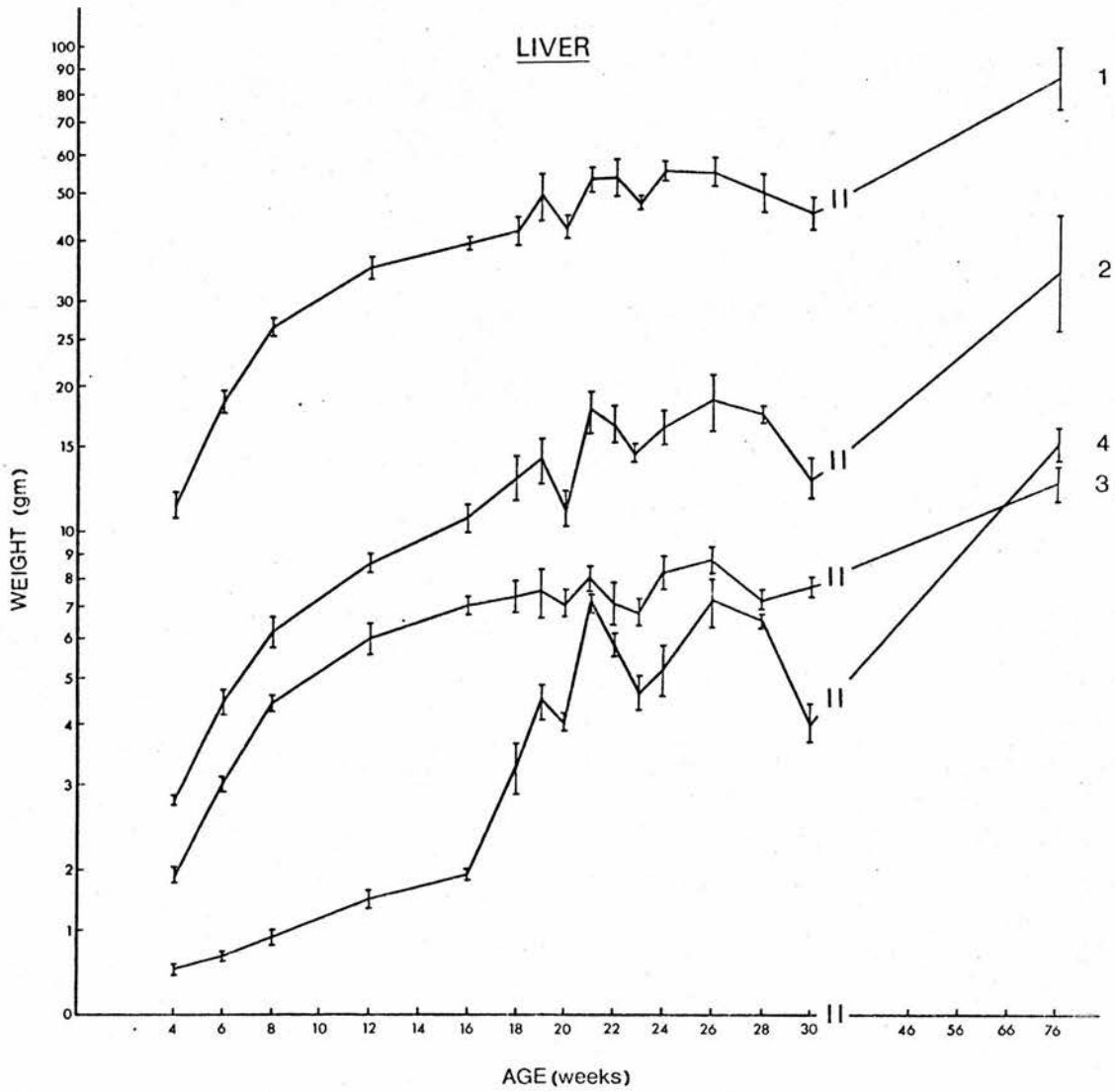

FIG. 3 Wet weight, dry weight, protein and fat changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Wet weight. 2. Dry weight. 3. Protein. 4. Fat.

at 76 weeks of age it weighs about 86 g. The variation in the liver weight perhaps has to do with the different metabolism of each bird at each age. The chemical composition of the liver will be discussed later in the text (page 73).

In Fig. 4 the spleen is presented. Its weight varies with different ages of birds particularly in the first 19 weeks of age. This can be interpreted on the basis that in the young bird the spleen is more active and supplies the blood with white and red blood corpuscles, but when adult life approaches the bone marrows seem to take over this function from the spleen. Spleen in man is 2% of body weight; in the dog it is 7% but in the bird it is considerably smaller (0.13% in the adult bird).

Fig. 5 gives the wet and dry weights of the fowl's kidneys at different ages. The kidneys are, in contrast to the mammal, situated in a series of body cavities in the interior surface of the illium of the bird. A further difference in birds is that most of the water is reabsorbed in the cloaca and lower colon and the urine is voided as a whitish paste of urate intermixed with the faeces. The kidneys can be seen to increase rapidly in weight in the first 8 weeks and thereafter there is a steady but considerably slower growth up to 76 weeks, which could indicate that even at 76 weeks somatic growth has not yet ceased. The kidneys growth in this respect is interesting because

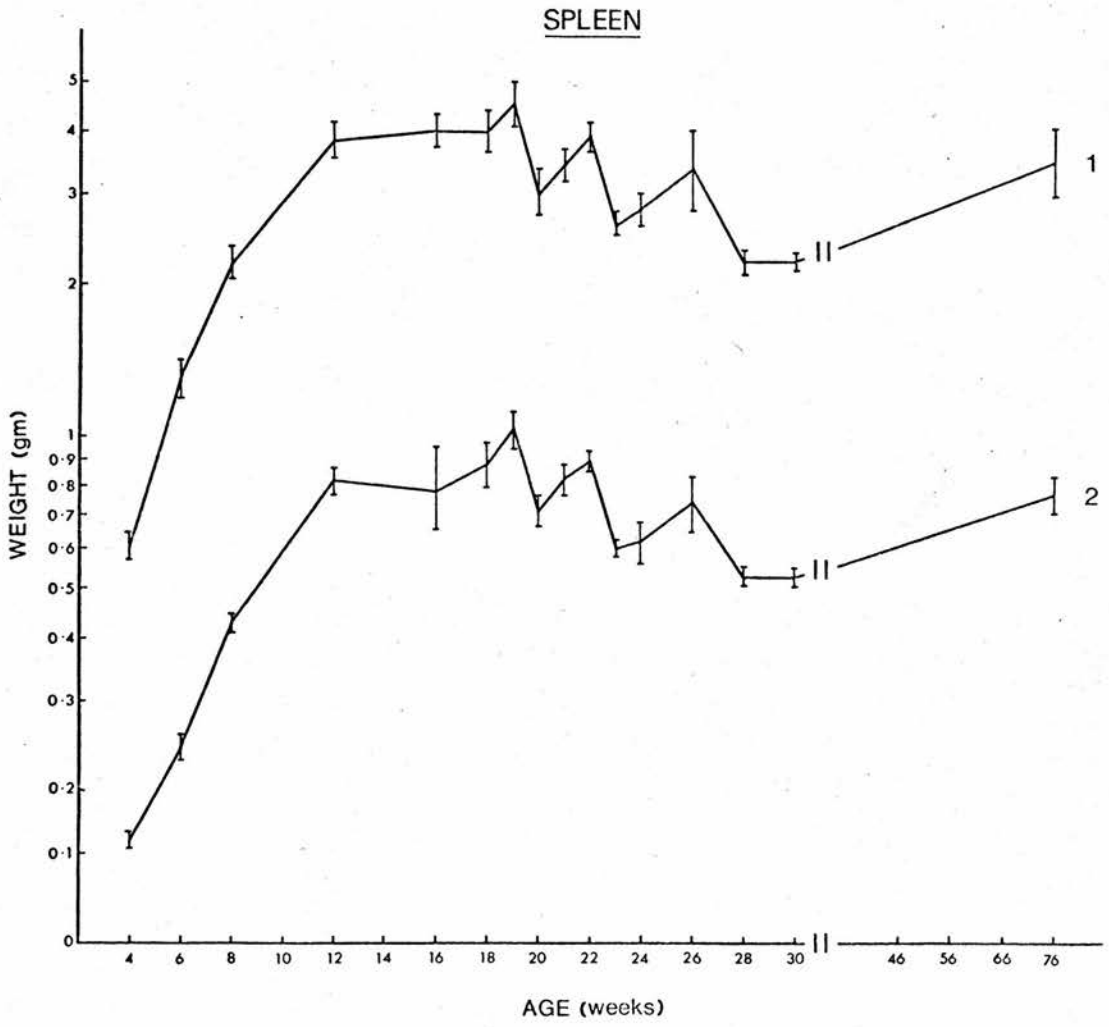

FIG. 4 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Wet weight. 2. Dry weight.

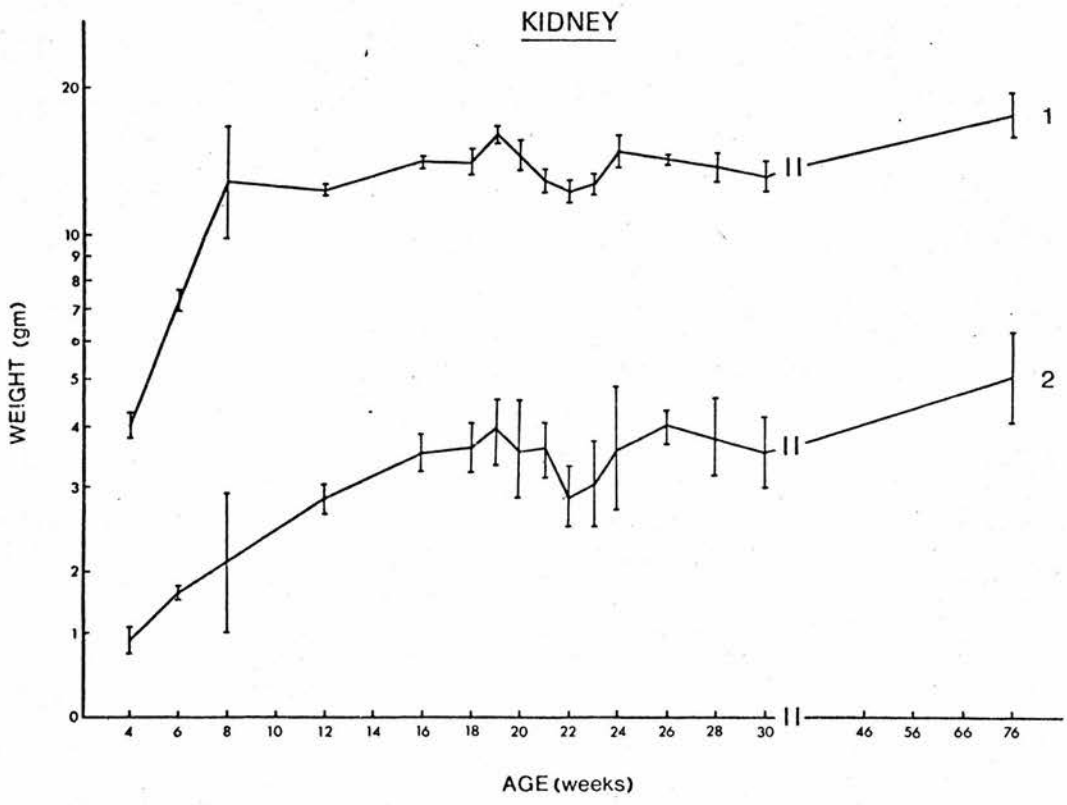

FIG. 5 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Wet weight. 2. Dry weight.

they can only increase in weight if the bony cavities in which they lie closely confined increase. Kidney growth, as with other aspects of growth, can be noted to be checked at the initiation of sexual function.

Fig. 6 shows the weight of the adrenal glands and the changes with aging in the laying fowl. They weigh about 0.03 g at 4 weeks rising to approximately 0.22 g at 18 weeks of age then drop to about 0.16 g at 76 weeks of age. This sort of change in the weight of the adrenal glands is difficult to explain. It would seem that after the onset of sexual maturity the need for corticosteroid type hormones is possibly supplied from the ovary and hence the adrenal glands are less important.

The next discussion in this section on the anatomical aspects is the presentation of the remaining organs under two headings, namely, the digestive system and the reproductive system.

1. The digestive system of the domestic fowl is quite different from those of mammals and other large animals. Birds have no teeth with which to chew their food, the teeth and the lips having been replaced by the horny beak. The food, therefore, is essentially swallowed in lumps and sent down to the crop where it is stored temporarily and softened. From the crop the food then passes on in small quantities for grinding in the gizzard after it has been mixed with gastric juices secreted by the glandular stomach

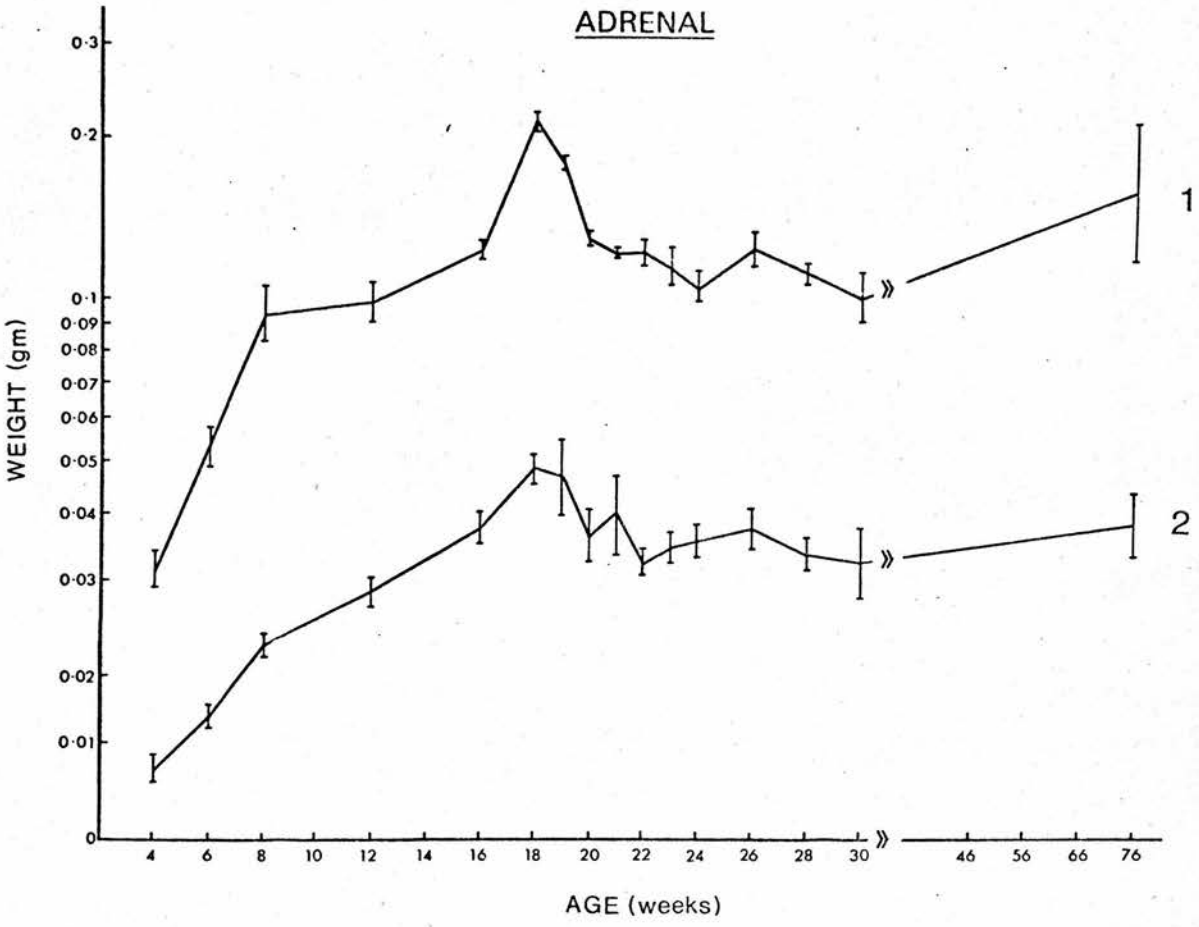

FIG. 6 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Wet weight 2. Dry weight.

(proventriculus). Fig. 7 gives the wet and dry weights of the gizzard of the domestic layer type hen at different ages. The gizzard itself is a powerful muscular grinding apparatus with a tough, horny lining. Its weight ranges from about 9 g at 4 weeks of age up to about 30 g at 76 weeks. The increase in the gizzard weight during aging is probably associated with the increase in food intake. The increase is highest between the fourth and twelfth week, but from 16 weeks onwards there is not much difference in its weight. In the gizzard food is finely ground with the aid of retained grit to make more efficient use of the whole grains and coarse, fibrous constituents of the feed. From the gizzard the partly digested food passes into the gut beginning with the small intestine where most of the digestion takes place. The large intestine of the domestic fowl has a small capacity and is of minor importance in digestion. It consists of a short colon and two caeca. Fig. 8 presents the weight of the gut and the changes in weight that occur during aging. The changes in the gut as presented in Fig. 8 are almost parallel to those in the gizzard. This is not surprising since these two organs are obviously closely associated with each other in the process of digestion. The increase in the weight of the gut can also be explained on the same basis as that for the gizzard. The weight of the gut varies quite widely during the fowl's life. At 4 weeks of age the weight is about 28 g and at 76 weeks it increases to about 140 g.

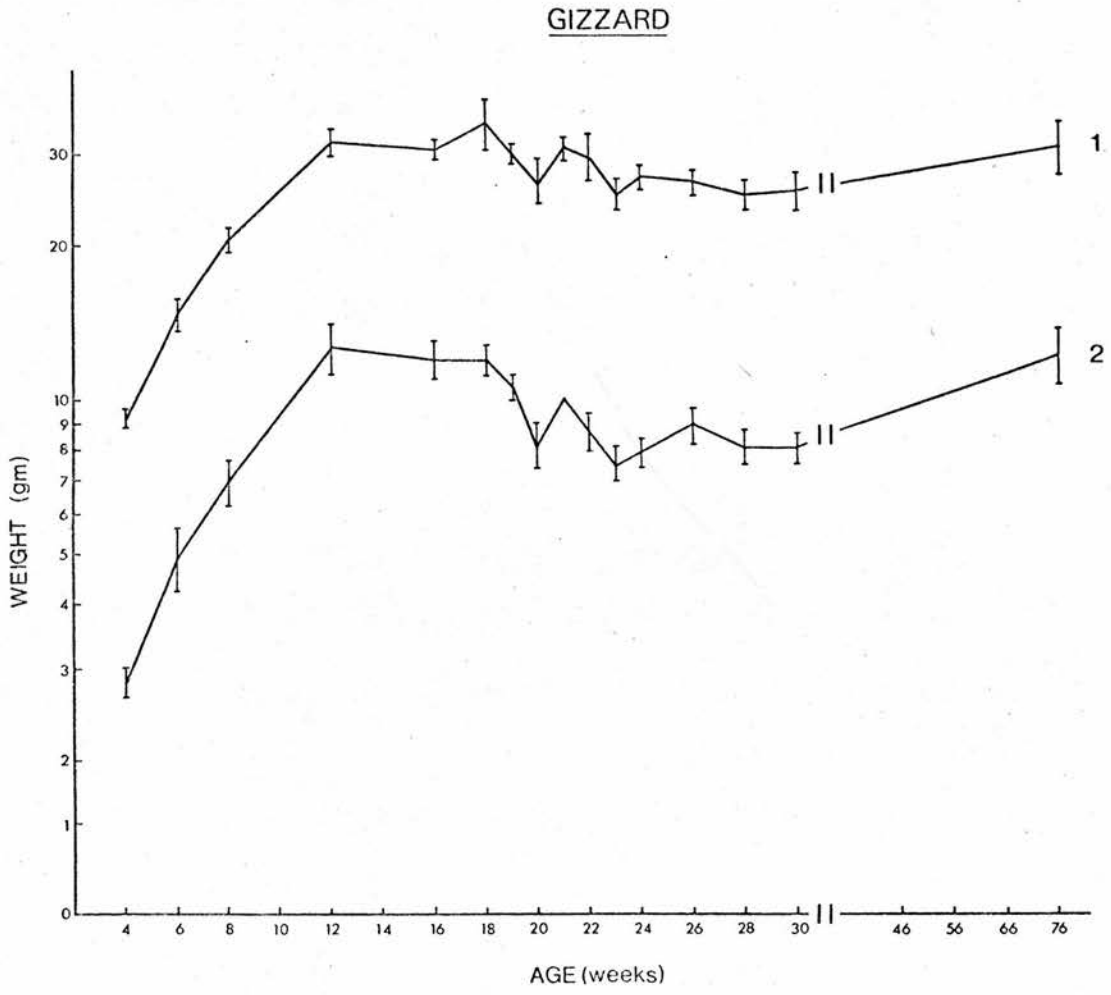

FIG. 7 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Wet weight. 2. Dry weight.

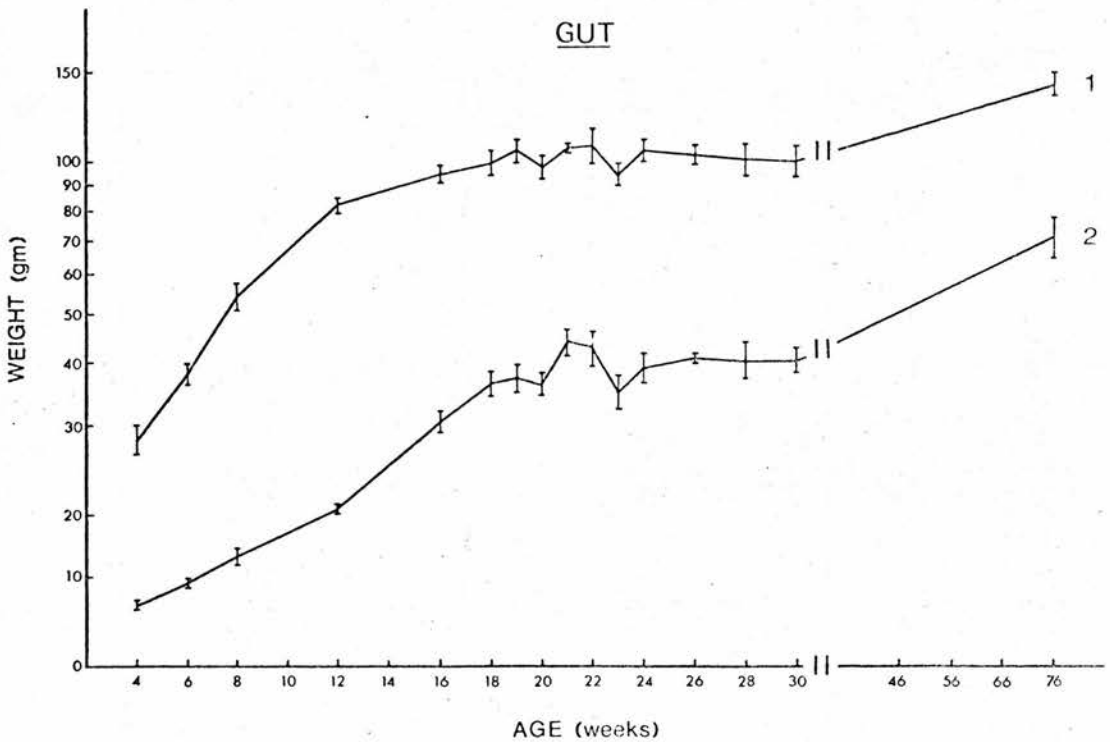

FIG. 8 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n= 6 ♂♂. 1. Wet weight. 2. Dry weight.

It comprises about 4% to 7% of the body weight.

2. The reproductive system consists mainly of two parts, the single ovary and the single oviduct. These two organs are situated in the interior cavity of the abdomen on the left side of the body cavity. The right ovary and oviduct disappear during embryonic life. The oviduct of a modern, hybrid laying hen weighs about 60 g and is about 72 cm long (Wyburn et al, 1970). The oviduct is also divided into various phases of secretory activity where each division makes a characteristic contribution to the different layers of white surrounding the yolk (Sturkie, 1965 and Draper, 1966).

Fig. 9 shows the wet weight and the dry weight of the ovary of the layer type hen during different ages. In this figure the last maturing follicles have been removed because the main interest is in ovarian tissue not yolk material. Usually 3 to 6 follicles are greatly enlarged in a functioning ovary. These would contain about 30 g to 40 g of yolk substance. The ovary is found near the left kidney and consists of a great number of follicles which vary greatly in size and weight from 20 g down to micrograms. In these follicles there is the ovum surrounded by the yolk substance. At the time of ovulation the follicle sheds the yolk into the body cavity of the bird where the infundibulum, which is the first part of the oviduct, captures it. Fig. 10 shows the growth of the oviduct at different ages. From

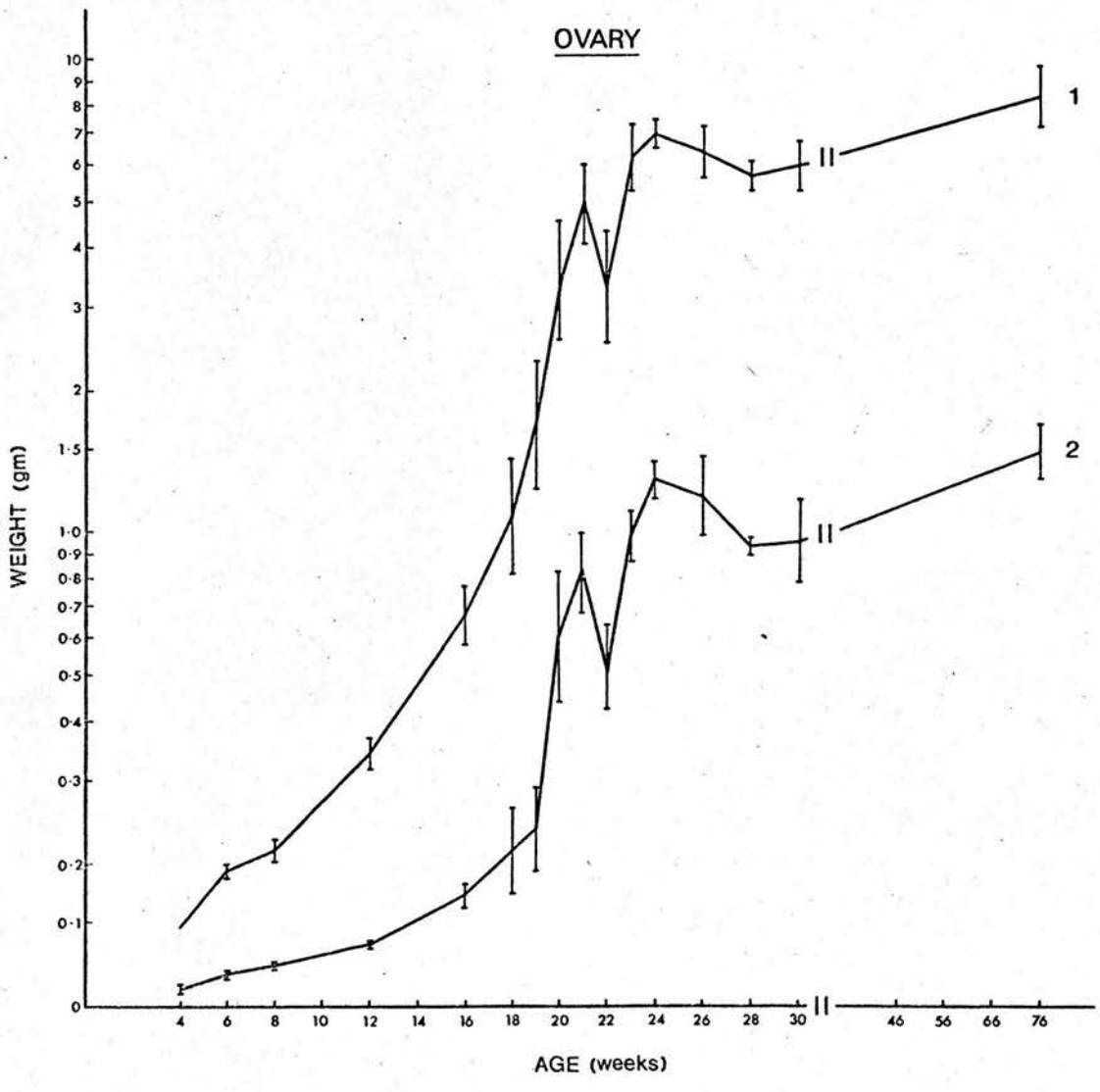

FIG. 9 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Wet weight, 2. Dry weight.

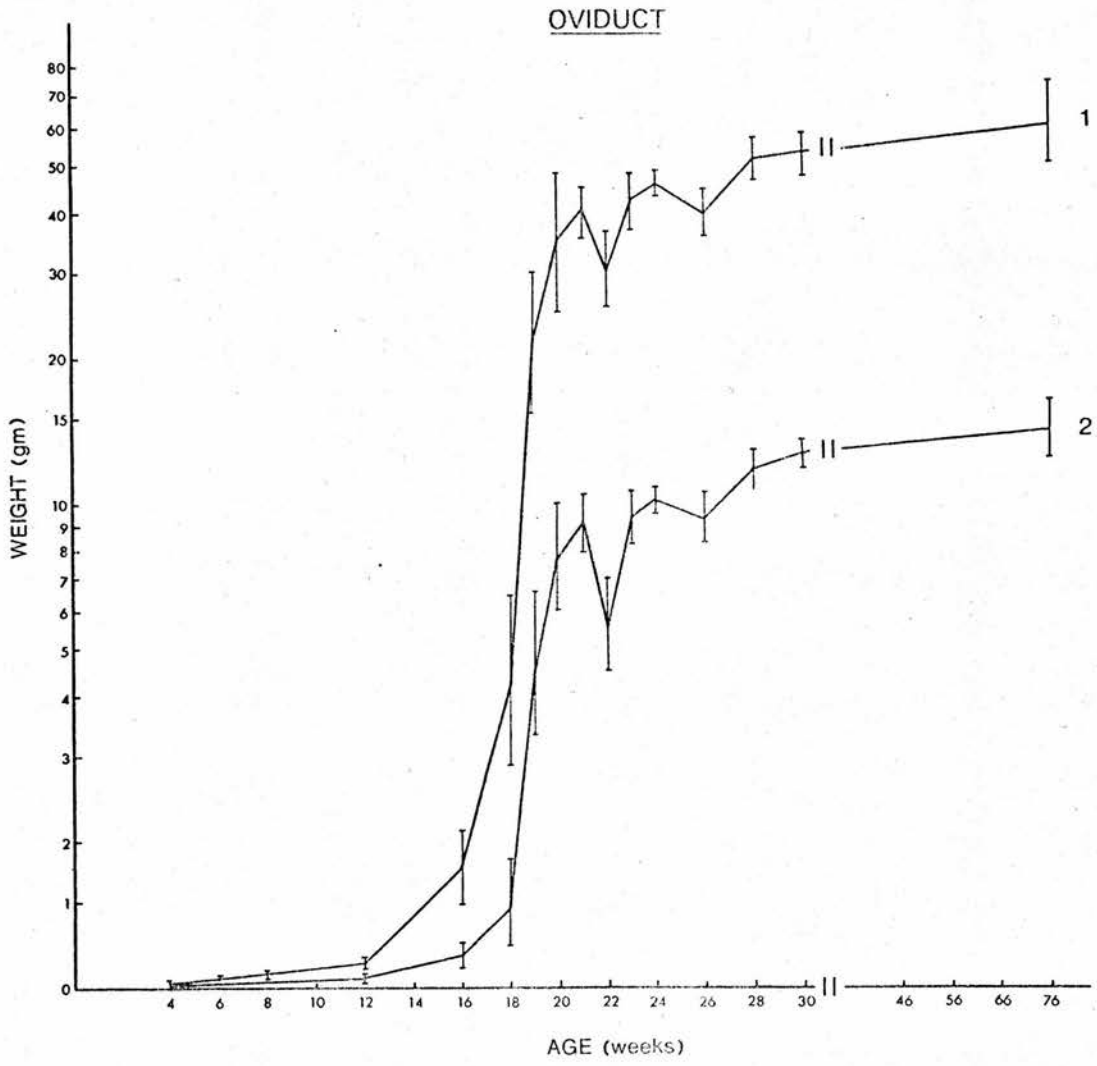

FIG. 10 Wet weight and dry weight changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Wet weight 2. Dry weight.

Figs. 9 and 10 one can observe a large difference between these two organs and the remaining organs in the way they grow during the period from birth to maturity. It is striking to see that the life of the bird appears to be divided into two parts or as if one is dealing with two different birds. At first, the bird seems to be growing normally; the live weight is increasing and the cell mass is increasing continuously for about the first 18 weeks of age then suddenly, within a matter of 3 to 4 weeks, the bird changes: the ovary becomes bigger and a great number of follicles of all different sizes appear. The oviduct becomes larger in size and weight and the reproductive system which was apparently non-existent just 4 weeks previously becomes obvious and active. This sudden change in the fowl's life has somehow influenced the actual pattern of the muscle mass growth. This is clear, particularly when the bird becomes fully sexually mature at the age of 24 weeks. This picture of changes in the bird's life is presented more clearly in Figs. 11 and 12 where all the birds involved were represented individually. From these two figures one may observe that almost nothing happens during the first 18 weeks of life except for the actual growth itself. However, by the beginning of the 19th week there is evidence of sexual maturity in some birds because of the presence of an egg in the oviduct. By the end of the 24th week all birds involved in this experiment were sexually mature.

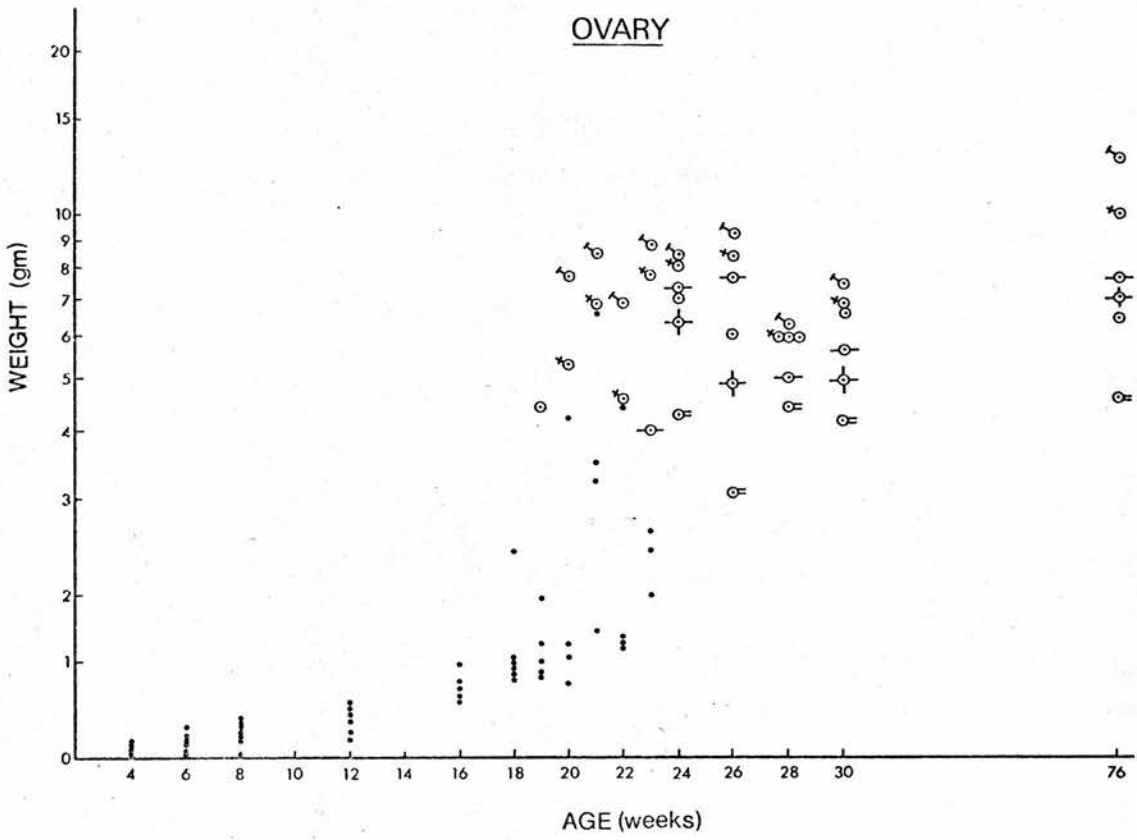

FIG 11 Individual changes in ovary weights with age in layer type hens. The presence of an egg in the oviduct is indicated by a varient of the symbol ⊹. The same symbol in each age group is used to denote the ovary and oviduct weights from the same bird.

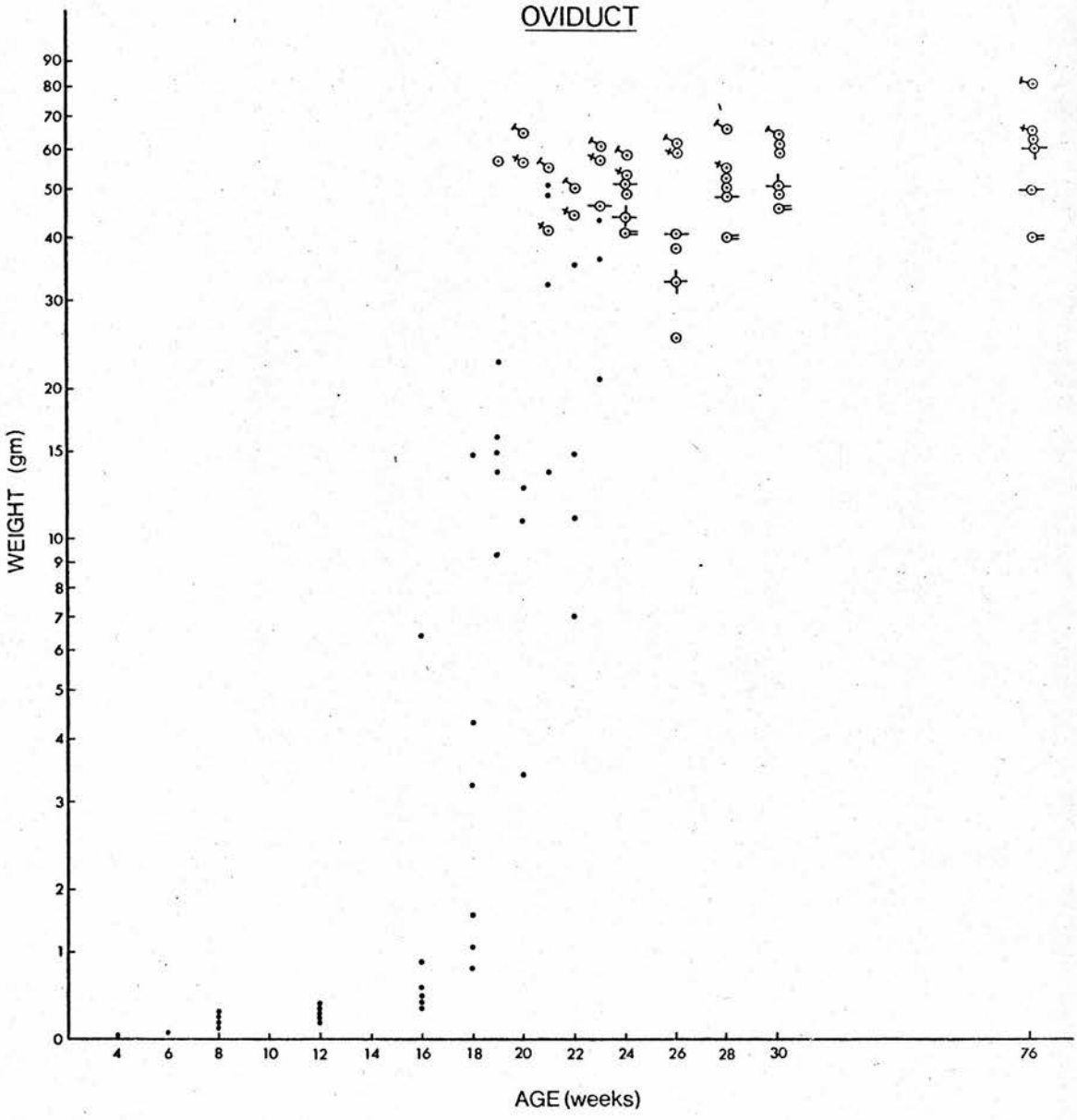

FIG. 12 Individual changes in oviduct weights with age in layer type hens. The presence of an egg in the oviduct is indicated by a varient of the symbol ⊹. The same symbol in each age group is used to denote the ovary and oviduct weights from the same bird.

Ovary mean results (Fig. 9) suggest that there is a steady growth of ovarian tissue until the 18th week when growth, both in wet mass and, possibly of greater importance, dry matter, significantly accelerates to reach a plateau level in about 2 weeks. In Fig. 11, looking at the individual results which are taken from a group of presumably homogeneous birds reared under identical conditions, the first egg appeared in week 19 but it was not until week 24 that all birds were in lay, a gap of 5 weeks in this group. From Fig. 11, and considering the ovary weights before the first egg at week 19, it would seem that the final acceleration of growth prior to the first ovulation must take from 1 to 2 weeks with an increase of weight from 1 g to 4 g.

Oviduct development parallels ovarian development in that the first eggs were observed in birds with oviducts of some 50 g weight (Fig. 12) in week 19. The smallest oviduct associated with an egg weighed 25 g. By week 16 oviducts were beginning to show obvious signs of growth although, in most birds, it is at this stage a tiny tube (about 0.5 g) with one exception, where the oviduct is 6 g. By 19 weeks all oviducts are clearly approaching maturity with one at maturity (weight 55 g) as evidenced by the production of an egg (weight 60 g). As with the ovary, maturation takes a surprisingly short time, particularly in the massive oviduct which, from Fig. 12 would

seem to grow from about 1 g to 50 g or more in about 2 weeks. In oviducal maturation there is also a time dispersion of about 5 weeks (19 to 24) in this population, although as indicated for an individual bird, it is probably only 14 days or even less. The graph of the average oviducal weights (Fig. 10) as far as the maturation of the group is concerned, is somewhat misleading as egg production would seem to be initiated and completed from weeks 16 to 19. This is not so when individual birds are considered, and this more accurate assessment is needed to interpret the overall growth rate disturbances which are apparent in all the growth rate graphs between weeks 19 and 26. This characteristic interruption of the regular growth rate pattern will be seen to be present in the second group of birds (Thornber 808) and is reflected quite clearly in the various chemical anatomical compartments to be considered in section 4.2.

4.2. The Chemical Aspects

The anatomical studies of some internal organs of the domestic fowl (Gallus domesticus) presented in the previous section were made during the early and advanced life of heavy, layer type hens (Thornber 909).

In this section chemical studies are described using light hybrid, layer type hens of high productivity (Thornber 808). These studies were begun early in the life of the bird before maturity was reached and ended at about 1.5 years

of age. They were initiated to investigate the integration of the complex interacting processes that take place during the life cycle of the fowl.

There are four major chemical anatomical compartments which make up an animal, (1) the cell mass, which is mainly protein, (2) the fat mass, (3) the water content and (4) the bone mass, in which calcium phosphate is dominant. Fig. 13 presents live body weight and breast and thigh muscle weight, and it should be noted that these birds are much lighter than the 909's in Fig. 1. Fig. 13 also shows that the live weight of the bird is still increasing at 1.5 years. The increase in the body weight per unit of time declines after the 18th week of age. From 18 to 26 weeks of age, i.e. the period of sexual maturation, the growth rate curve displays considerable irregularities, not only in body weight, but in all other constituents studied. Fig. 13 shows how breast and thigh muscle weights reflect the changes in body weight. Live body weight decreases by 167 g from 1549 g at 23 weeks to 1382 g at 24 weeks of age. A similar fall in the growth curve of Thornber 909 is shown in Fig. 1. The breast and thigh muscles decrease by 29 g and 15 g respectively between the 23rd and 24th week of age. Table 4 gives the mean of live body weight, breast and thigh muscle weight during the practical life cycle of the domestic fowl. Fig. 14 shows the total solids, protein and fat contents of the breast muscle in the layer type hen and the changes

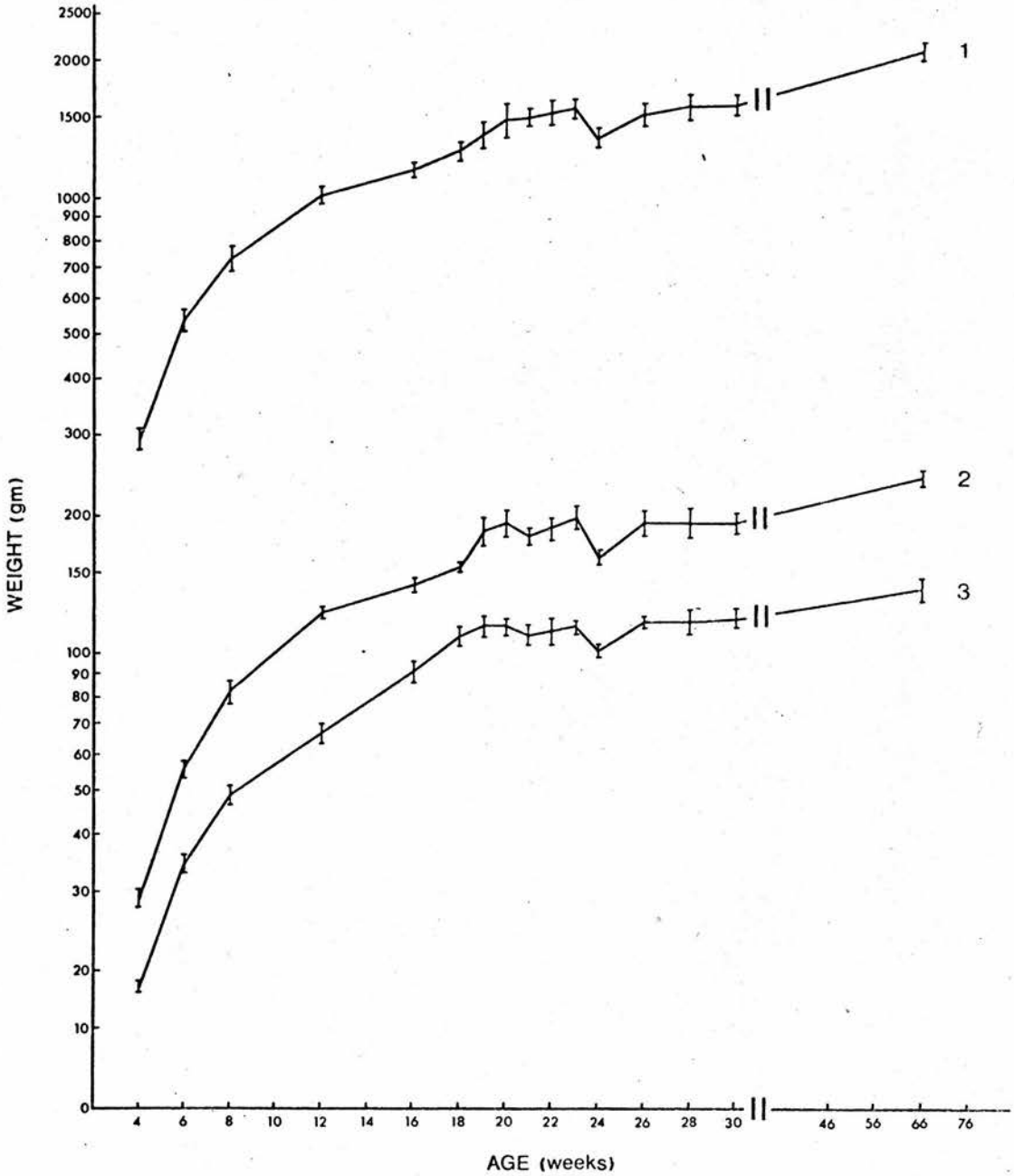

FIG 13 Live weight, breast muscle wet weight and thigh muscle wet weight changes in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Live weight. 2. Breast muscle wet weight. 3. Thigh muscle wet weight.

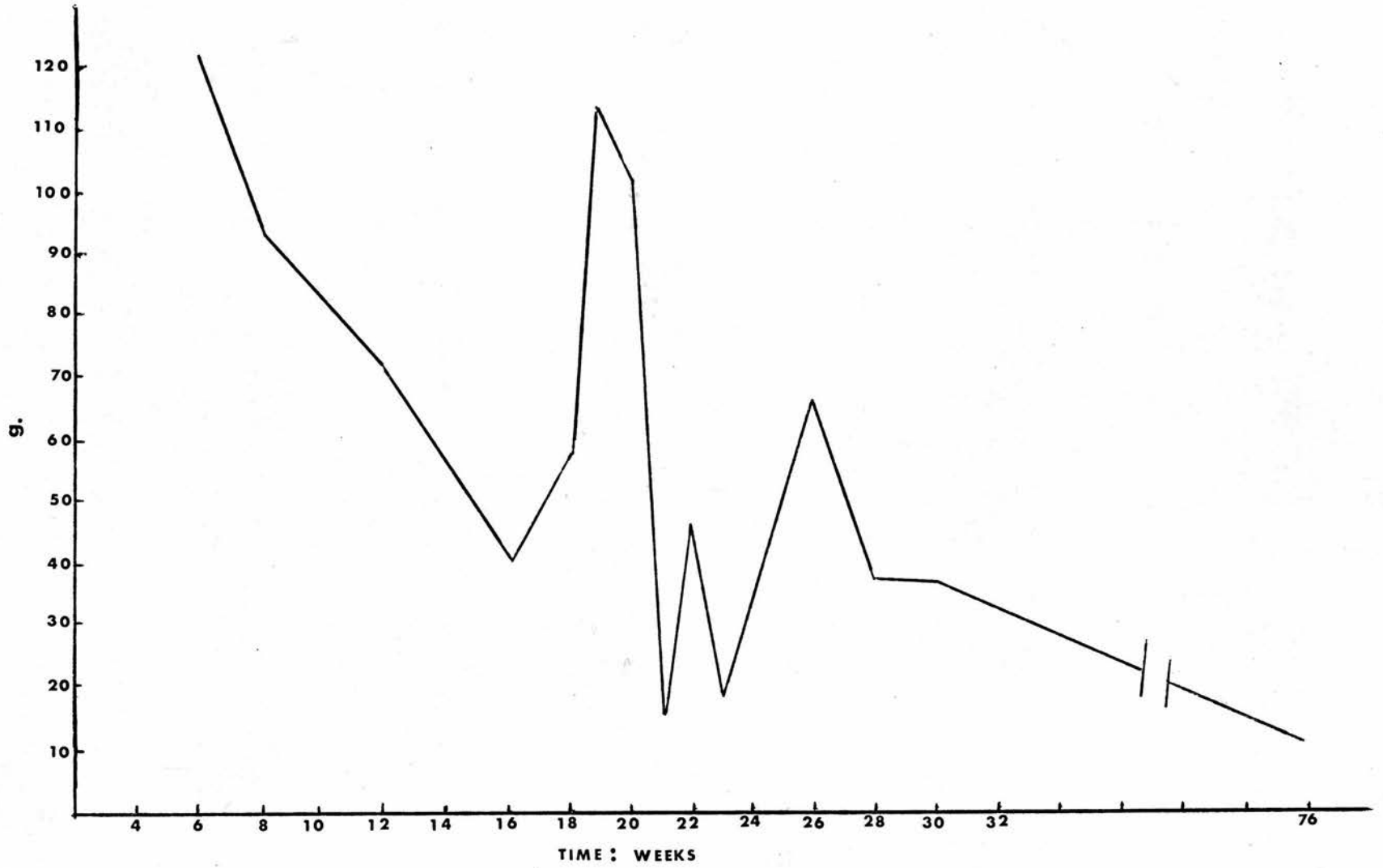

FIG. 13a BODY GROWTH VELOCITY PER WEEK

TABLE 4

Average live weight, breast and thigh muscle wet weight (g)

Results are means of six birds (± SEM)

Age (weeks)	Live weight	Breast weight	Thigh weight
4	295 ± 10.9	29 ± 1.4	17 ± 0.9
6	539 ± 11.2	58 ± 1.4	35 ± 0.6
8	725 ± 23.1	83 ± 2.6	48 ± 1.9
12	1016 ± 23.0	125 ± 4.0	77 ± 1.8
16	1141 ± 30.8	143 ± 5.8	91 ± 2.4
18	1252 ± 40.6	154 ± 5.1	100 ± 2.1
19	1366 ± 68.0	187 ± 11.4	115 ± 5.1
20	1469 ± 79.6	192 ± 12.2	114 ± 2.1
21	1484 ± 51.1	173 ± 6.4	108 ± 4.7
22	1530 ± 64.9	185 ± 10.6	113 ± 6.3
23	1548 ± 51.8	194 ± 6.5	115 ± 3.5
24	1381 ± 31.0	164 ± 5.0	100 ± 1.8
26	1514 ± 53.0	186 ± 10.2	118 ± 3.5
28	1588 ± 67.8	190 ± 11.2	117 ± 7.2
30	1588 ± 40.0	189 ± 5.4	119 ± 3.3
76	2053 ± 41.0	240 ± 4.1	138 ± 4.4

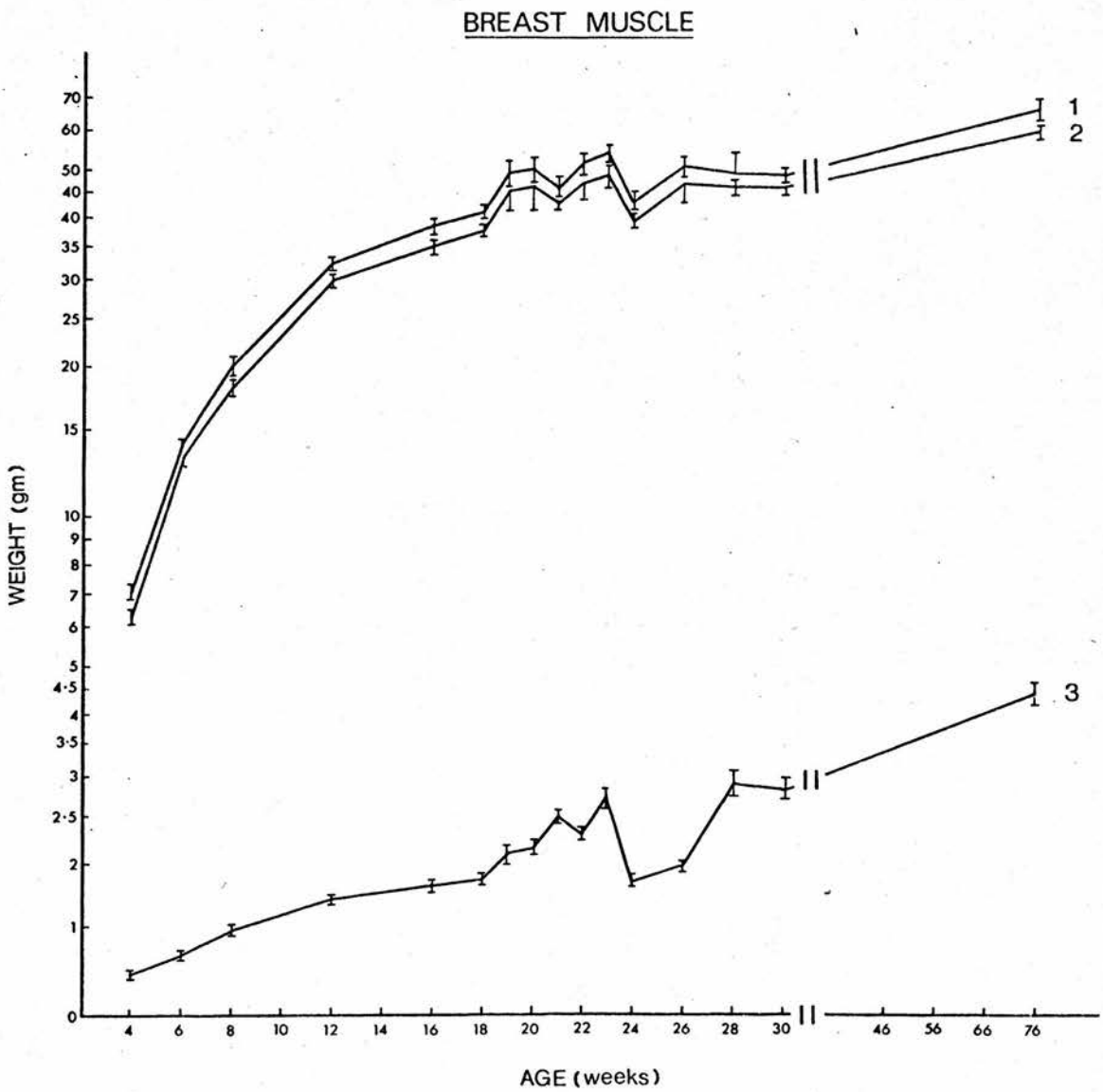

FIG.14 Total solids, protein and fat changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Total solids. 2. Protein. 3. Fat.

with aging. In breast muscle, total solids and protein increase in amount in almost the same manner as does wet weight, but the accumulation of fat does not follow the same pattern. This is not surprising since breast muscle fat content is low while its protein content is high. At 24 weeks of age, when the bird becomes sexually mature, the content of total solids, protein and fat decreases as does the wet weight.

Fig. 15 gives the thigh muscle total solids, protein and fat contents during the period of 4 to 76 weeks of age. It is apparent that the thigh muscle drops in total solids, protein and fat weight at the 24th week of age following the same pattern as the breast muscle. Fig. 16 shows the weight and composition of the body carcass, that is the part of the body remaining after the breast and thigh muscles of both sides have been removed, and the changes that occur during aging.

The true meaning of the overall growth curve is given by the composite Fig. 16 which shows the breakdown of the carcass, less the breast and thigh muscle masses, into its major constituents. Although the overall live weight gain appears uniform, except for the small digressions about the time of sexual maturity, this is far from true of the constituents. It is particularly noteworthy how, after the 17th week, the rate of accumulation of protein falls off and the rate of accumulation of fat increases. After 30

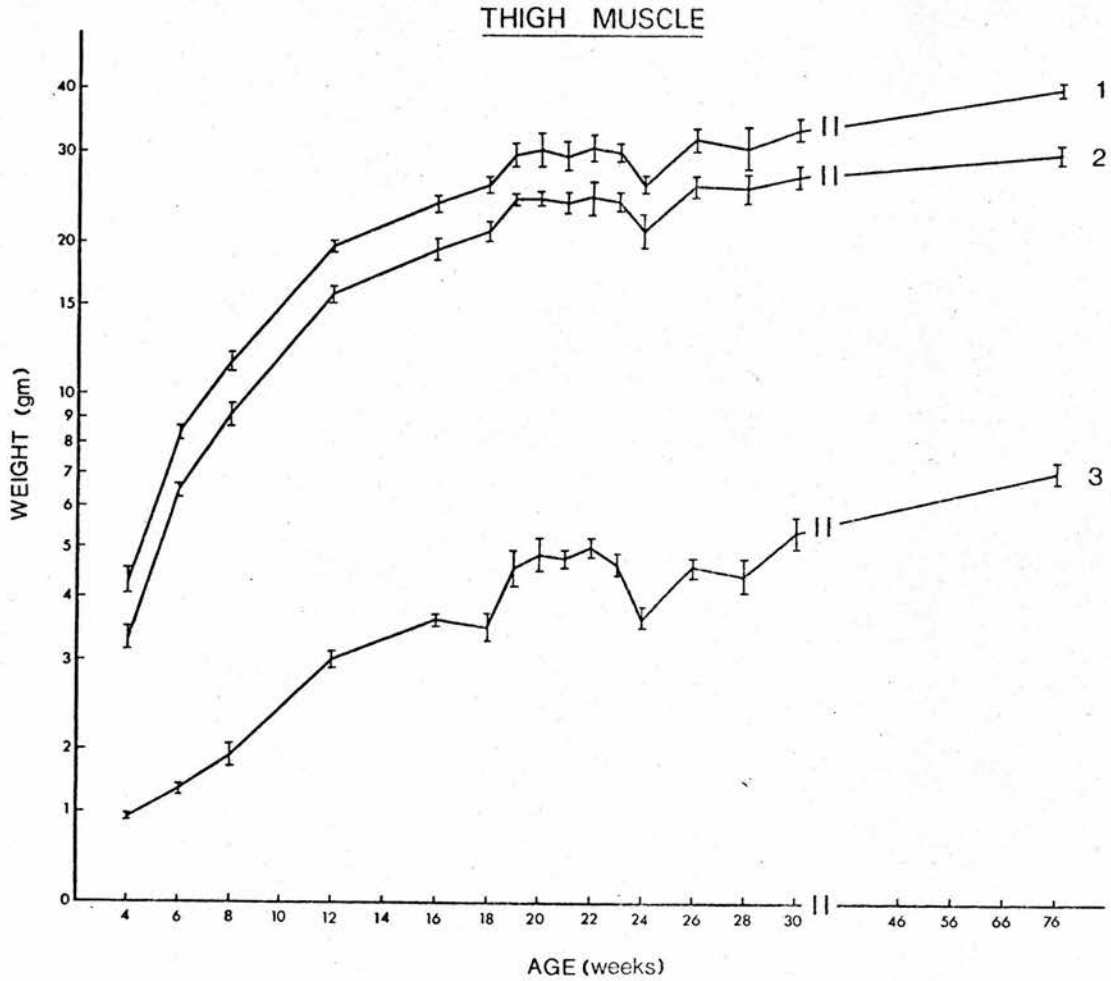

FIG. 15 Total solids, protein and fat changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♀♀. 1. Total solids. 2. Protein. 3. Fat.

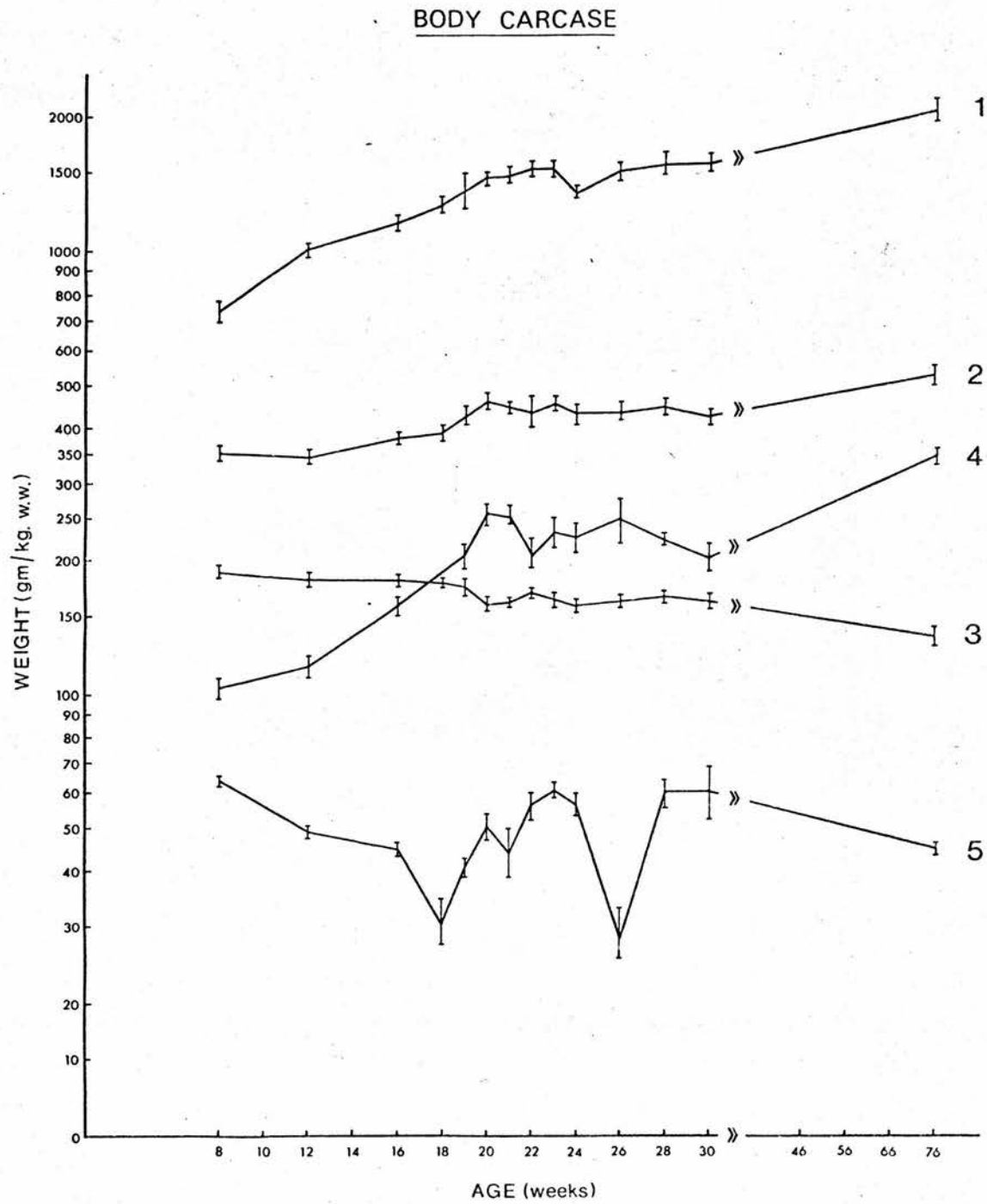

FIG.16 Live weight, crude carcase total solids, protein, fat and Δ solids changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂.
1. Live weight. 2. Total solids. 3. Protein. 4. Fat. 5. ▲ Solids.

weeks it seems that in the slow growth phase of the hen in maximum productivity, fat is being laid down at 7.7 times the rate of protein accumulation in the carcass. When the total body carcass is considered (Fig. 17), that is, body carcass plus breast and thigh muscles, fat accumulation is still 5.5 times greater than protein accumulation.

The body carcass fat at 30 weeks of age was 196 g (see Fig. 16) and at 76 weeks of age was 485 g. Therefore, in 46 weeks fat has increased by 289 g corresponding to an increase of 6.3 g of fat per week. Protein, on the other hand, at 30 weeks of age was 157 g and at 76 weeks of age was 194 g giving a difference of 37 g in 46 weeks, corresponding to an increase of 0.81 g per week. It appears that fat is accumulating at 7.7 times the rate of protein. For the total body carcass fat was 204 g at 30 weeks (see Fig. 17) increasing to 498 g at 76 weeks, giving an increase of 294 g in 46 weeks, corresponding to an increase of 6.4 g of fat per week. Protein increased by only 1.15 g per week during this period while fat continued to accumulate at 5.5 times the rate of protein. Thus the dominant factor in weight increase in the later phases is the fat component. In fact, fat rather than protein becomes dominant in growth from about the 17th week of age, while protein accumulation tends to slow down as the animal ages (see also Table 5).

It is worth noting from Fig. 16 how the body carcass,

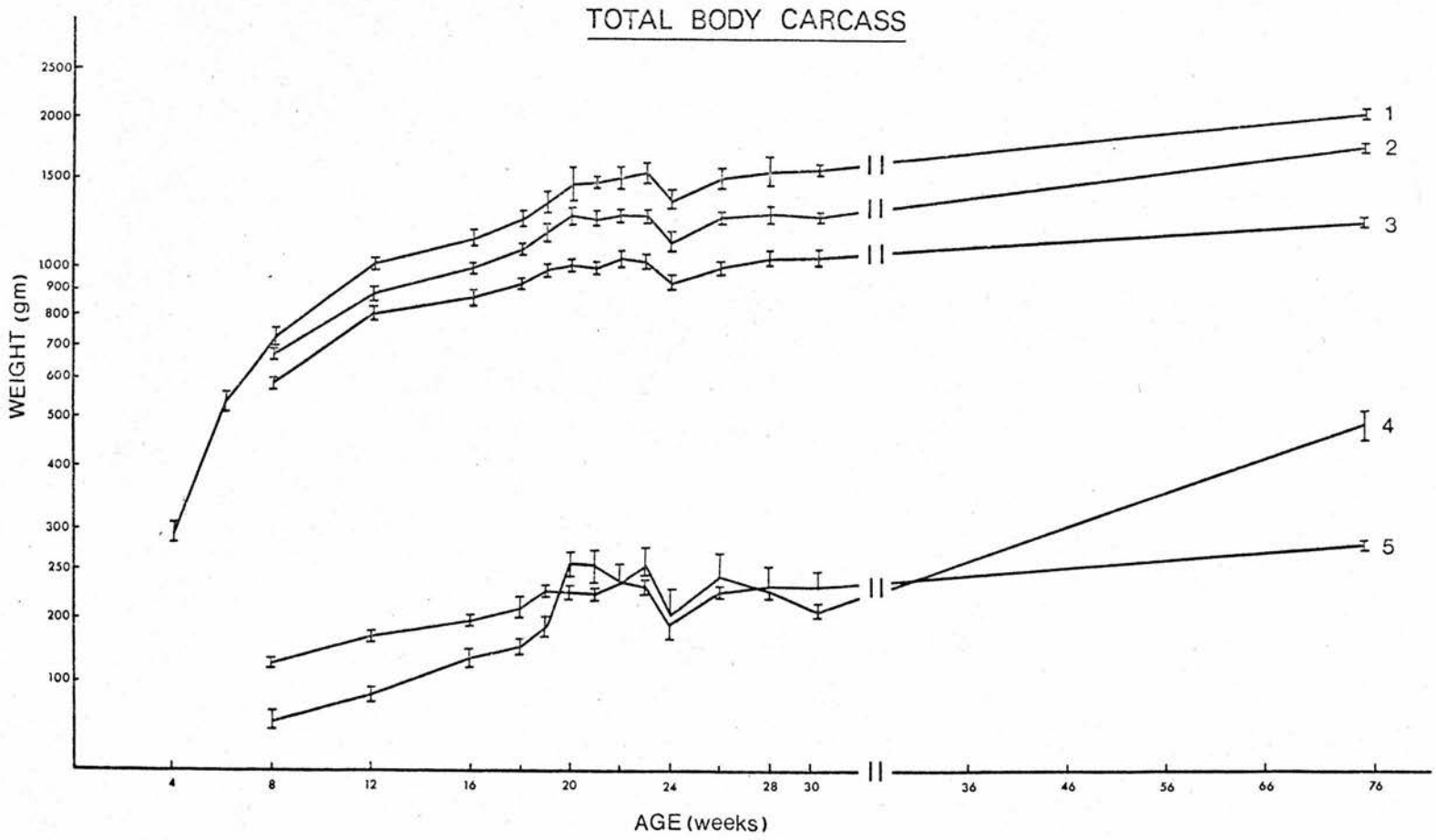

FIG. 17 Live weight, Total body carcass, Total body carcass fat-free, fat and protein changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Live weight. 2. Total body carcass. 3. Total body carcass fat-free. 4. Total body fat. 5. Total body protein.

TABLE 5

Mean weights of body carcass composition of the domestic fowl (g)

Results are means of six birds (± SEM)

Age (weeks)	Wet weight	Total solids	Protein	Fat	Δsolids
8	502 ± 15.5	177 ± 6.9	93 ± 3.5	52 ± 3.3	32 ± 1.2
12	689 ± 50.6	237 ± 6.1	125 ± 2.9	80 ± 5.1	32 ± 1.3
16	759 ± 20.7	290 ± 9.6	136 ± 3.2	120 ± 8.2	34 ± 1.4
18	833 ± 30.7	328 ± 20.1	149 ± 4.9	154 ± 20.5	25 ± 2.5
19	879 ± 44.9	371 ± 28.0	155 ± 5.7	179 ± 21.4	37 ± 2.6
20	968 ± 57.5	451 ± 33.3	154 ± 5.9	248 ± 23.3	49 ± 4.7
21	975 ± 33.8	445 ± 18.1	157 ± 5.8	246 ± 11.3	42 ± 5.0
22	979 ± 36.9	425 ± 23.8	165 ± 6.3	205 ± 16.6	55 ± 3.8
23	969 ± 33.6	443 ± 22.4	157 ± 4.0	227 ± 17.9	59 ± 4.1
24	870 ± 30.2	376 ± 21.9	138 ± 2.4	197 ± 19.2	41 ± 3.4
26	946 ± 22.9	417 ± 19.9	153 ± 4.2	233 ± 19.1	31 ± 4.2
28	987 ± 48.9	442 ± 19.6	163 ± 8.2	219 ± 8.5	60 ± 4.0
30	961 ± 30.2	411 ± 18.9	157 ± 4.0	195 ± 16.4	59 ± 5.1
76	1408 ± 24.6	738 ± 22.6	194 ± 6.0	485 ± 23.2	59 ± 5.4

derived from the live weight minus the fat, protein and water content, apparently moves to a new level after sexual maturity after some fluctuations during the process of sexual maturation. As this measure is by difference and so subject to considerable error, one must be careful about its interpretation; however, most of it must be mineral and the increased level during sexual maturation could be some measure of the increased mineral store consequent upon the necessity for shell formation. This is discussed further in connection with the mineral estimations on page 83.

The most important component of a carcass, in the agricultural context, is the muscle mass and a false impression of its growth is given by changes in body weight owing to the dominant factor in growth being the fat mass, particularly in the early stages of sexual maturity. Evidence of the complex processes of growth is presented in Fig. 17 where the constituents of the whole bird are given. Fig. 17 also gives the live body weight, total body carcass, protein and fat contents from 8 weeks to 76 weeks of age. The total body carcass, both fat-free and with fat, runs parallel to that of the live body weight during the course of the bird's life. The protein and fat situation is similar to that found in the body carcass data presented in Fig. 16. Fat is the dominant factor in increasing body weight after the age of 19 weeks and more so as age advances. Conversely, protein is the dominant

component in the early stages of life. However, by the end of the 18th week the fat accumulation becomes dominant and is responsible for an increasing proportion of the bird's weight.

The mineral contents of the body presented in Fig. 18 are principally calcium, phosphorus, potassium, magnesium and sodium, and are expressed in millimoles per kilogram wet weight. Phosphorus has been estimated in the form of phosphate (PO_4). Phosphorus and calcium are the dominant elements in the mineral composition of the body. These two elements are related mainly to the bone mass of the fowl. Phosphorus performs a very important function in the structure of the cytoplasm and the nucleus of all living cells but quantitatively, it is predominantly the bone mass which is important as a $Ca_3 (PO_4)_2$ type of mineral. Fresh bone of the adult domestic fowl contains about 11.5% calcium. Potassium, which is mainly in the intracellular fluid, is one of the ~~major~~ components of the cell mass. Sodium, on the other hand, is a major component of the extracellular fluid. Magnesium is also known to be one of the important elements in the cytoplasm of both animal and plant cells, however, approximately half of the magnesium of the body is present in the bone mass. The practical importance of these elements in physiology is of special interest. By estimating the mineral content of an animal one can measure, in an indirect way, the four major components of the animal body. From the calcium results it is possible to estimate

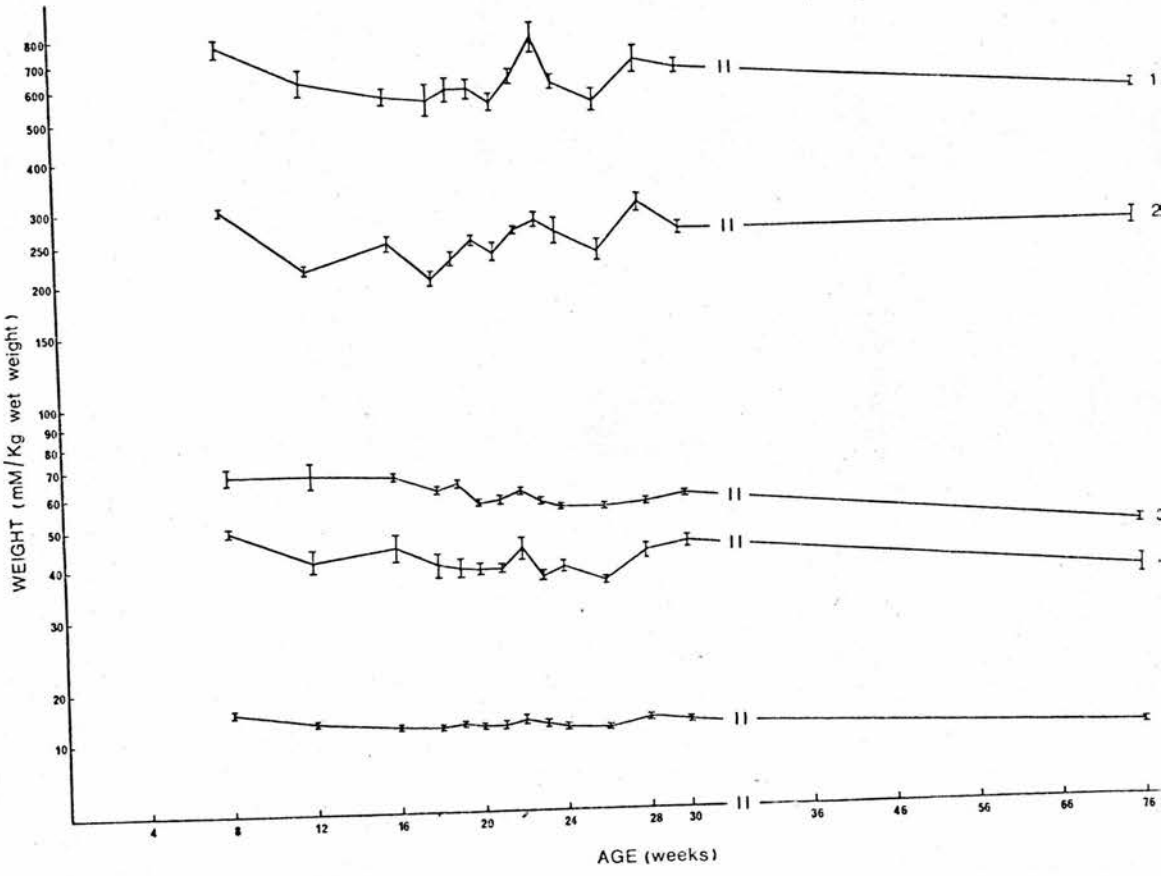

FIG. 18 Total body mineral changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♀♀.

1.- PO^4 2.- Ca 3.- K 4.- Na 5.- Mg

the bone mass, from the potassium and magnesium results one can estimate the cell mass and from sodium the extracellular fluid can be estimated. The methods used in these calculations are discussed on page 65.

Fig. 18 shows that phosphorus and calcium has a high concentration when the bird is very young, and this tends to decrease by the onset of sexual maturity. Potassium and magnesium also appear to follow this pattern, starting with a relatively high concentration in early life which gradually reduces to a low concentration in later years. This follows from the dominance of fat in later life. Sodium also shows a higher concentration in early life which decreases with aging probably for the same reason.

Since skeletal muscle is the largest cell mass of the body and is comprised mainly of protein, attention has been directed to the way in which this muscle grows and develops. The muscles investigated were breast and thigh muscles because, in Gallus domesticus, these are representative of typical white and red muscles. However, according to George and Berger (1966) the breast muscle, which consists mainly of white muscle cells, consists of two different muscles, namely, the pectoralis and the supracoracoideus. These show some difference in cellular organisation and biochemical properties but these differences are not significant for the present considerations and for the purpose of the present studies, pectoralis (major and minor) and

the supracoracoideus were treated as one entity. The thigh muscles were also treated as one muscle mass and comprised all the muscles associated with the femur. Fig. 19 gives the breast and thigh muscle total solids, protein and fat changes with aging in the layer type hen. The wet weights of these two muscles have already been given in Fig. 13 which shows a difference in the weights of these two muscles, breast muscle being the dominant muscle mass. From the time of hatching and during the first week of life the situation is the reverse in that thigh muscles are heavier than breast muscles (Dickerson, 1960 and Draper, 1968). The same picture is presented in Fig. 19 where the breast muscle total solids, protein and fat is heavier than that of the thigh muscle during the normal life of the fowl. A point which has been observed during these studies is that during the approach of the sexual maturity of the bird, that is, commencing at approximately the 24th week of age, the skeletal muscle of the fowl displays irregularities in weight and in composition. A point of interest is the sharp, highly significant decrease in weight from week 23. A comparison between breast and thigh muscle was carried out to compare the degree of decrease which occurred in each muscle both in terms of weight and composition during the period of 23 to 24 weeks of age when all birds involved in this experiment were sexually mature. Table 6 gives the average contents of total solids, protein and fat for both breast and thigh muscles from 4 to 76 weeks of age.

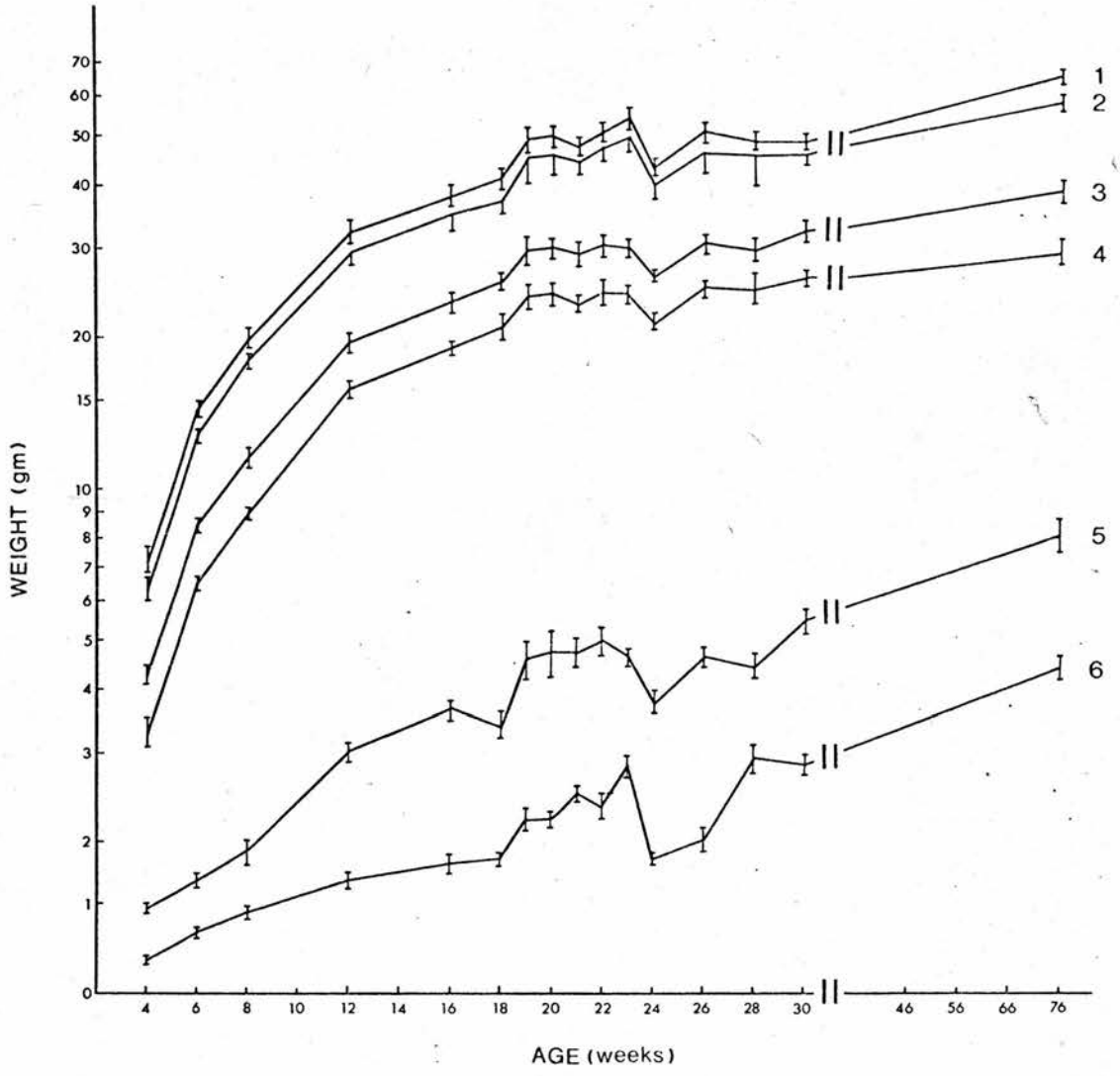

FIG. 19 Breast and thigh muscle total solids, protein and fat changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Breast muscle total solids. 2. Breast muscle protein. 3. Thigh muscle total solids. 4. Thigh muscle protein. 5. Thigh muscle fat. 6. Breast muscle fat.

TABLE 6

Average contents of total solids, protein and fat of breast and thigh muscle (g)
Results are means of six birds (± SEM)

Age (weeks)	Total solids		Protein		Fat	
	Breast	Thigh	Breast	Thigh	Breast	Thigh
4	7.1 ± 0.4	4.2 ± 0.2	6.3 ± 0.3	3.2 ± 0.1	0.3 ± 0.01	0.8 ± 0.04
6	14.5 ± 0.3	8.4 ± 0.1	13.0 ± 0.3	6.5 ± 0.1	0.6 ± 0.02	1.3 ± 0.05
8	20.2 ± 0.8	11.6 ± 0.5	18.0 ± 0.7	9.1 ± 0.3	0.8 ± 0.04	1.8 ± 0.21
12	32.5 ± 1.0	19.6 ± 0.4	30.1 ± 1.0	15.8 ± 0.4	1.4 ± 0.04	3.0 ± 0.13
16	38.4 ± 1.6	23.7 ± 0.7	35.3 ± 1.5	19.1 ± 0.4	1.6 ± 0.08	3.6 ± 0.12
18	40.9 ± 1.2	25.7 ± 0.6	37.4 ± 1.4	20.8 ± 0.7	1.7 ± 0.05	3.3 ± 0.25
19	49.1 ± 3.3	29.8 ± 1.4	45.3 ± 3.0	24.1 ± 1.2	2.2 ± 0.16	4.5 ± 0.30
20	50.2 ± 3.4	30.2 ± 1.5	46.2 ± 3.1	24.2 ± 1.3	2.1 ± 0.09	4.7 ± 0.38
21	46.3 ± 1.9	29.2 ± 1.3	42.5 ± 1.7	23.5 ± 1.0	2.5 ± 0.10	4.7 ± 0.26
22	51.6 ± 3.1	30.5 ± 1.5	47.3 ± 2.9	24.4 ± 1.4	2.3 ± 0.19	4.9 ± 0.29
23	54.3 ± 3.3	30.1 ± 0.7	50.1 ± 1.7	24.5 ± 0.8	2.8 ± 0.16	4.6 ± 0.17
24	43.0 ± 2.0	25.8 ± 0.5	40.3 ± 1.1	21.1 ± 0.4	1.7 ± 0.07	3.6 ± 0.17
26	50.3 ± 2.9	31.6 ± 1.0	46.7 ± 2.5	25.6 ± 0.7	1.9 ± 0.14	4.6 ± 0.25
28	48.8 ± 3.6	30.5 ± 1.9	45.6 ± 3.7	25.4 ± 1.6	2.8 ± 0.14	4.4 ± 0.34
30	49.9 ± 1.7	33.0 ± 1.0	46.2 ± 1.5	26.7 ± 0.6	2.8 ± 0.19	5.4 ± 0.28
76	65.5 ± 1.0	38.9 ± 1.2	59.5 ± 1.0	29.2 ± 0.9	4.4 ± 0.23	8.1 ± 0.25

Table 7 compares the decrease in weight and chemical composition between the breast and thigh muscles during the interesting period of 23 to 24 weeks of age. From this Table it is clear that the breast muscle decreases more than that of the thigh muscle in weight and in composition. Fig. 20 shows identical results to those presented in Fig. 19 but in the former case they are displayed in terms of grams per kilogram wet weight. It is still apparent that the decrease occurring in the skeletal muscle composition during the duration of sexual maturity is higher in the breast than in the thigh muscle. A comparison between breast and thigh muscle is given in Table 8 and the results expressed per kilogram wet weight. Figs. 21 and 22 give the mineral contents of the breast and thigh muscles of the fowl at different ages. These are potassium, sodium, magnesium and calcium. Breast muscle has higher potassium and magnesium levels and lower sodium and slightly lower calcium levels than the thigh muscle. This could be due to the fact that breast muscle is richer in protein than thigh muscle and that thigh muscle has more water than breast muscle. As will be seen the composition of muscles from hatching to 2 weeks of age is somewhat different. The advantages of knowing the mineral composition of an animal has already been mentioned in the text. The aim of measuring the mineral composition is to gain some detailed knowledge of cell growth, bone mass accumulation and extracellular fluid volume, that is, the major components of the body.

TABLE 7

The decrease and the rate of reduction (%) in the composition of breast and thigh muscles during 23 to 24 weeks of age (g)

Age (weeks)	Breast Muscle			Thigh Muscle		
	Total Solids	Protein	Fat	Total Solids	Protein	Fat
23	54.3 ± 3.3	50.1 ± 1.7	2.8 ± 0.16	30.0 ± 0.76	24.2 ± 0.81	4.6 ± 0.17
24	43.0 ± 2.0	40.3 ± 1.1	1.7 ± 0.07	25.8 ± 0.53	21.1 ± 0.47	3.6 ± 0.17
Decrease (g)	11.3 $P<.02$	9.8 $P<.001$	1.1 $P<.001$	4.2 $P<.001$	3.1 $P<.001$	1.0 $P<.01$
Rate of Reduction (%)	21.0	19.5	38.6	13.8	13.7	20.9

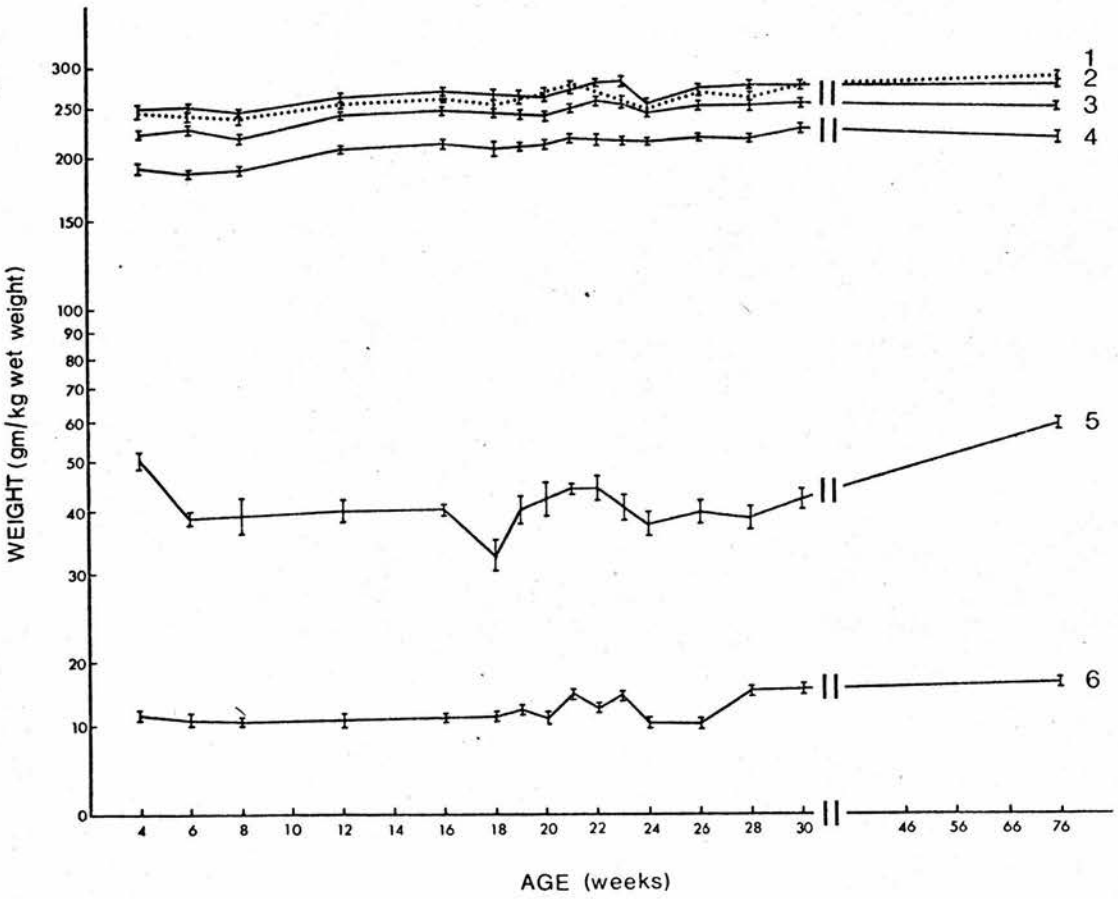

FIG. 20 Breast muscle and thigh muscle total solids, protein and fat changes with aging in layer type hens. Values are mean ± SEM. For each point n= 6 ♀♀. 1. Thigh muscle total solids. 2. Breast muscle total solids. 3. Breast muscle protein. 4. Thigh muscle protein. 5. Thigh muscle fat. 6. Breast muscle fat.

TABLE 8

The decrease and the rate of reduction (%) in the composition of breast and thigh muscles during 23 to 24 weeks of age (g/kg w. wt.)

Age (weeks)	Breast Muscle			Thigh Muscle		
	Total solids	Protein	Fat	Total solids	Protein	Fat
23	280 ± 2.1	258 ± 0.5	14.9 ± 0.50	263 ± 1.3	214 ± 1.4	40.0 ± 2.1
24	261 ± 2.0	245 ± 1.3	10.6 ± 0.62	260 ± 2.1	213 ± 1.0	37.0 ± 1.6
Decrease	19 $P<.001$	13 $P<.001$	4.3 $P<.001$	3 $P<0.3$	1 $P<0.8$	3.0 $P<0.3$
Rate of Reduction (%)	6.7	5.2	28.8	1.1	0.2	7.5

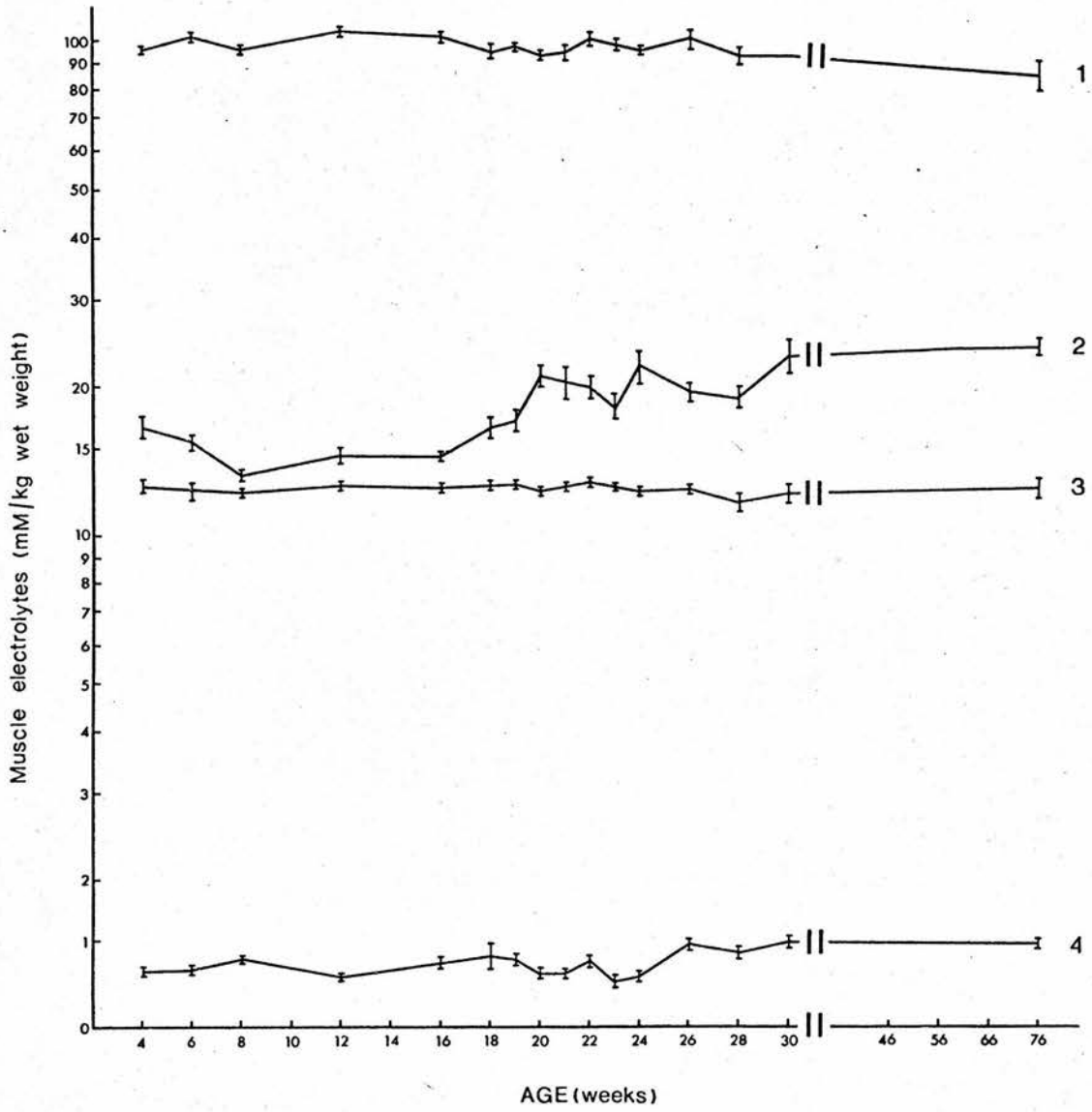

FIG. 21 Breast muscle potassium, sodium, magnesium and calcium changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♀♀. 1. Potassium. 2. Sodium. 3. Magnesium. 4. Calcium.

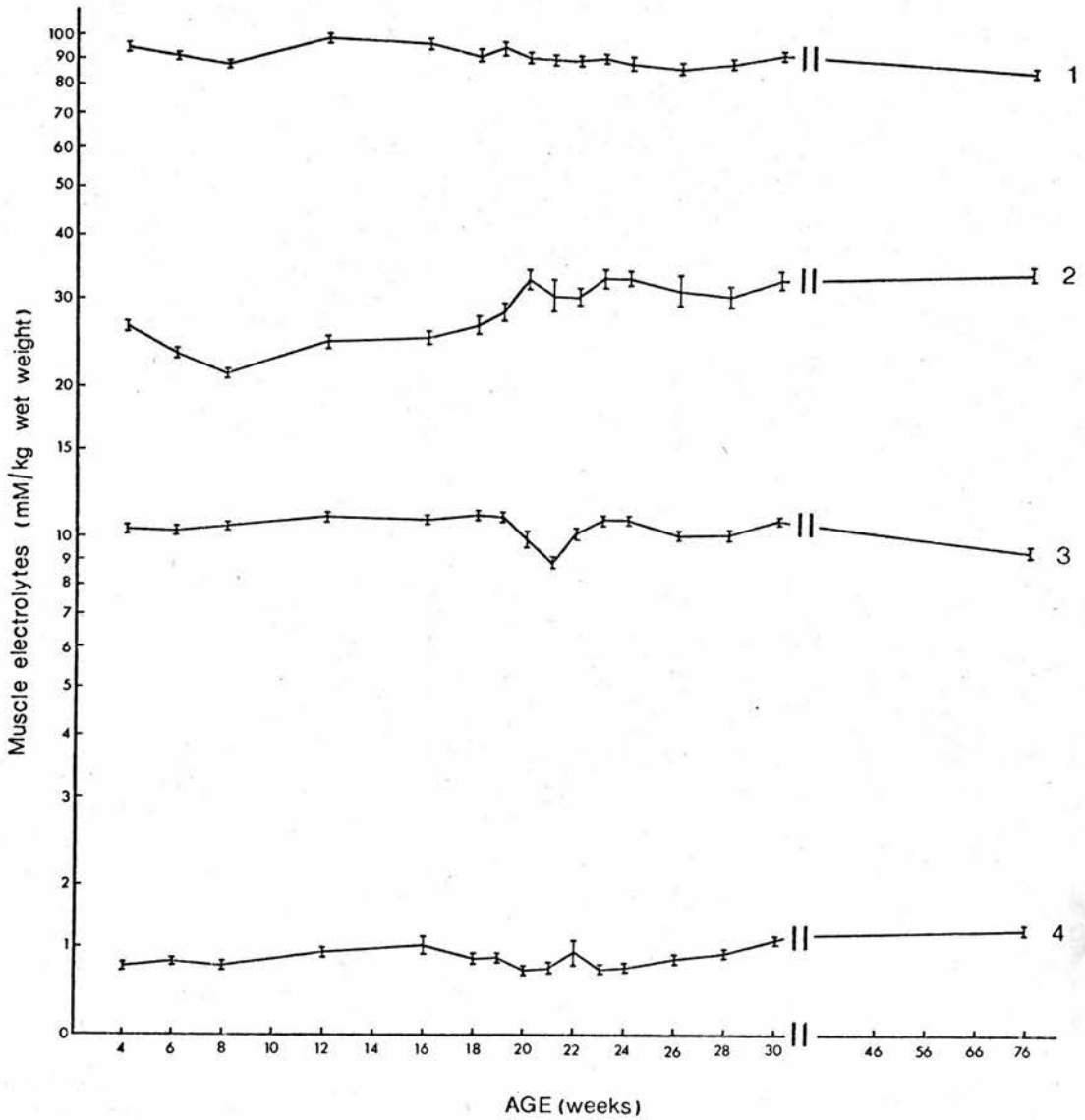

FIG. 22 Thigh muscle potassium, sodium, magnesium and calcium changes with aging in layer type hens. Values are mean ± SEM. For each point n = 6 ♀♀. 1. Potassium. 2. Sodium. 3. Magnesium. 4. Calcium.

Estimations of muscle mass and bone mass can be found with difficulty by direct dissection of the animal and these estimates can be compared with those calculated from the mineral content. Cell growth measurement, if it can be estimated by the use of minerals, would be more valuable than the growth rate of the animal itself, because fat accumulation can obscure the accumulation of other tissues such as muscles (see Figs. 16 and 17). Miller (1968) stated that the metabolically active part of the adipose tissue may account for as little as 2% of the wet weight of the tissue, which is almost invisible. He also pointed out that fat deposition is limited by the number of adipose cells available and the capacity of these cells to accept lipids. Evans (1969) reported that fat is a relatively late growth component and its deposition is not associated with the onset of chemical maturity. The increase in fat deposition during the growth of the animal is regarded to be as a result of hyperplasia and hypertrophy (Miller, 1968; Passmore and Draper, 1970 and Widdowson, 1970). In the present studies potassium and magnesium were used to estimate cell mass and sodium and potassium were used to partition total body water into extracellular and intracellular fluid compartments. Calcium was used in the estimation of bone mass. Table 9 gives the average contents of potassium, magnesium, sodium and calcium of the two distinguished muscle cells of the domestic fowl, namely, the breast muscles and the thigh muscles. Table 10 gives

TABLE 9

Average ~~contents~~ CONCENTRATIONS of potassium sodium, magnesium and calcium of the muscle of the fowl.
(mM/kg w. wt.)

Results are means of six birds (± SEM)

Age (weeks)	Potassium		Magnesium		Sodium		Calcium	
	Breast	Thigh	Breast	Thigh	Breast	Thigh	Breast	Thigh
4	95.3 ± 1.7	94.9 ± 2.70	12.5 ± 0.24	10.2 ± 0.14	16.4 ± 0.60	26.2 ± 0.43	0.56 ± 0.03	0.75 ± 0.01
6	102.0 ± 1.3	91.9 ± 0.79	12.1 ± 0.47	10.3 ± 0.15	15.4 ± 0.45	23.4 ± 0.24	0.60 ± 0.01	0.80 ± 0.02
8	96.1 ± 0.9	87.7 ± 0.74	12.7 ± 0.11	10.9 ± 0.17	13.1 ± 0.30	21.6 ± 0.40	0.75 ± 0.01	0.75 ± 0.01
12	104.5 ± 1.3	99.2 ± 1.17	13.3 ± 0.18	11.3 ± 0.18	14.5 ± 0.54	24.7 ± 0.46	0.57 ± 0.00	0.94 ± 0.05
16	102.4 ± 0.4	97.2 ± 1.21	12.5 ± 0.19	10.6 ± 0.06	14.5 ± 0.17	25.0 ± 0.43	0.62 ± 0.01	1.07 ± 0.18
18	95.6 ± 1.4	91.5 ± 1.47	12.8 ± 0.08	11.1 ± 0.18	16.4 ± 0.70	26.6 ± 0.91	0.80 ± 0.17	0.83 ± 0.02
19	97.5 ± 0.9	95.0 ± 1.99	12.3 ± 0.13	11.6 ± 0.32	17.0 ± 0.70	28.2 ± 1.26	0.76 ± 0.05	0.84 ± 0.02
20	93.4 ± 1.2	89.9 ± 1.22	12.2 ± 1.10	10.0 ± 0.15	21.5 ± 0.62	32.9 ± 1.21	0.45 ± 0.02	0.74 ± 0.05
21	94.2 ± 2.0	88.9 ± 0.83	13.1 ± 0.16	10.1 ± 0.07	20.5 ± 1.46	30.2 ± 1.75	0.54 ± 0.04	0.78 ± 0.12
22	100.9 ± 1.3	89.6 ± 1.82	13.1 ± 0.17	11.2 ± 0.22	19.8 ± 0.92	30.2 ± 1.51	0.68 ± 0.01	0.95 ± 0.21
23	98.2 ± 1.3	90.7 ± 1.47	12.0 ± 0.13	10.7 ± 0.22	18.2 ± 1.08	33.1 ± 1.65	0.44 ± 0.05	0.71 ± 0.02
24	97.1 ± 1.6	90.7 ± 1.64	12.4 ± 0.16	10.7 ± 0.17	22.0 ± 1.43	33.0 ± 0.85	0.52 ± 0.01	0.72 ± 0.05
26	103.8 ± 2.3	86.4 ± 1.71	12.8 ± 0.10	10.2 ± 0.10	19.6 ± 0.73	31.2 ± 1.82	0.94 ± 0.05	0.81 ± 0.02
28	93.1 ± 2.2	88.0 ± 2.29	11.2 ± 0.28	9.8 ± 0.33	19.0 ± 0.81	30.6 ± 1.50	0.82 ± 0.05	0.92 ± 0.05
30	92.7 ± 2.8	91.7 ± 1.57	12.1 ± 0.29	10.1 ± 0.13	23.1 ± 1.87	33.0 ± 1.10	0.95 ± 0.07	1.13 ± 0.05
76	86.2 ± 3.3	85.2 ± 1.13	12.8 ± 0.33	9.5 ± 0.22	24.7 ± 0.61	34.0 ± 0.74	0.93 ± 0.07	1.24 ± 0.03

TABLE 9a

Average concentration of potassium, sodium, magnesium and calcium of the muscle of the fowl (mM/kg. w. wt. fat free)

Results are means of six birds (± SEM)

Age (weeks)	Potassium		Magnesium		Sodium		Calcium	
	Breast	Thigh	Breast	Thigh	Breast	Thigh	Breast	Thigh
4	96.4 ± 1.7	99.9 ± 2.70	12.6 ± 0.24	10.7 ± 0.14	16.5 ± 0.60	27.6 ± 0.43	0.57 ± 0.03	0.79 ± 0.01
6	103.1 ± 1.3	95.5 ± 0.79	12.2 ± 0.47	10.7 ± 0.15	16.5 ± 0.45	24.3 ± 0.24	0.61 ± 0.01	0.83 ± 0.02
8	97.2 ± 0.9	91.2 ± 0.74	12.8 ± 0.11	12.3 ± 0.17	13.2 ± 0.03	22.4 ± 0.40	0.76 ± 0.01	0.78 ± 0.01
12	105.6 ± 1.3	103.4 ± 1.17	13.4 ± 0.18	11.8 ± 0.18	14.6 ± 0.54	25.7 ± 0.46	0.58 ± 0.00	0.98 ± 0.05
16	103.6 ± 0.4	101.2 ± 1.21	12.6 ± 0.19	11.0 ± 0.06	14.6 ± 0.17	26.0 ± 0.43	0.63 ± 0.01	1.11 ± 0.18
18	96.7 ± 1.4	94.5 ± 1.47	12.9 ± 0.08	11.4 ± 0.18	16.6 ± 0.70	27.5 ± 0.91	0.81 ± 0.17	0.86 ± 0.02
19	98.7 ± 0.9	98.9 ± 1.99	12.4 ± 0.13	12.1 ± 0.32	17.2 ± 0.70	29.3 ± 1.62	0.77 ± 0.05	0.87 ± 0.02
20	94.4 ± 1.2	93.8 ± 1.22	12.3 ± 1.10	10.4 ± 0.15	21.8 ± 0.62	34.3 ± 1.21	0.45 ± 0.02	0.77 ± 0.05
21	95.6 ± 2.0	93.0 ± 0.83	13.3 ± 0.16	11.6 ± 0.07	20.5 ± 1.46	31.6 ± 1.75	0.55 ± 0.04	0.81 ± 0.12
22	102.2 ± 1.3	94.2 ± 1.82	13.3 ± 0.17	11.7 ± 0.22	20.0 ± 0.92	31.7 ± 1.51	0.69 ± 0.01	0.99 ± 0.21
23	99.4 ± 1.3	94.5 ± 1.47	12.1 ± 0.13	11.1 ± 0.22	18.4 ± 1.08	34.4 ± 1.65	0.44 ± 0.05	0.74 ± 0.02
24	98.1 ± 1.6	94.1 ± 1.64	12.5 ± 0.16	11.1 ± 0.17	22.2 ± 1.43	34.3 ± 0.85	0.52 ± 0.01	0.74 ± 0.05
26	104.9 ± 2.3	89.9 ± 1.71	12.9 ± 0.10	10.6 ± 0.10	19.8 ± 0.73	32.5 ± 1.82	0.95 ± 0.05	0.84 ± 0.02
28	94.5 ± 2.2	91.4 ± 2.29	11.3 ± 0.28	10.2 ± 0.33	19.3 ± 0.81	31.8 ± 1.50	0.83 ± 0.05	0.95 ± 0.05
30	94.1 ± 2.8	96.0 ± 1.57	12.3 ± 0.29	10.5 ± 0.13	23.4 ± 1.87	34.6 ± 1.10	0.96 ± 0.07	1.20 ± 0.05
76	87.8 ± 3.3	90.5 ± 1.13	13.0 ± 0.33	10.0 ± 0.22	25.2 ± 0.61	36.1 ± 0.74	0.95 ± 0.07	1.32 ± 0.03

TABLE 10

Calculation of cell mass from cell tissues on K basis

Values given for K are in millimoles

Age (weeks)	Amount of K in the body cells	(1) Amount of K/kg wet wt. of red and white muscle cells	(2) Cell tissue mass (g)	(3) Cell mass (g)	Live wt. (g)	Proportion of cell mass to the live wt. (%)
8	42.3 ± 1.4	91.9 ± 1.7	460 ± 20.1	391 ± 8.1	725 ± 23.1	53.9 ± 1.1
12	50.5 ± 1.2	101.8 ± 1.3	584 ± 26.1	500 ± 14.1	1016 ± 23.0	49.1 ± 2.0
16	65.5 ± 1.8	99.8 ± 1.3	656 ± 11.1	558 ± 18.1	1140 ± 30.8	48.9 ± 1.1
18	65.9 ± 2.0	93.5 ± 1.2	705 ± 14.2	599 ± 15.1	1252 ± 40.6	47.9 ± 1.8
19	74.4 ± 1.7	96.2 ± 0.9	772 ± 9.8	656 ± 21.1	1366 ± 68.0	48.1 ± 1.7
20	70.6 ± 2.7	91.7 ± 2.3	770 ± 10.1	654 ± 11.1	1469 ± 79.6	44.6 ± 0.9
21	70.0 ± 3.0	91.5 ± 2.4	764 ± 21.0	649 ± 10.6	1484 ± 51.1	43.8 ± 0.8
22	77.9 ± 2.9	95.3 ± 2.6	818 ± 16.1	695 ± 13.1	1530 ± 64.9	45.4 ± 0.9
23	72.1 ± 2.5	94.9 ± 1.4	743 ± 12.1	632 ± 21.1	1548 ± 51.8	41.0 ± 0.9
24	62.1 ± 1.5	93.9 ± 1.7	661 ± 10.1	562 ± 18.1	1381 ± 31.0	40.7 ± 1.2
26	68.8 ± 1.1	95.1 ± 1.7	723 ± 13.1	615 ± 22.0	1514 ± 53.0	40.6 ± 1.1
28	72.3 ± 2.0	90.6 ± 2.6	801 ± 15.2	681 ± 28.0	1588 ± 67.8	42.8 ± 1.8
30	74.6 ± 1.9	92.2 ± 0.9	809 ± 21.1	687 ± 20.2	1514 ± 40.0	45.5 ± 2.1
76	83.3 ± 2.6	88.7 ± 2.6	939 ± 23.2	798 ± 26.0	2053 ± 41.0	39.0 ± 0.7

Values given are mean of six birds (± SEM)

(1) The amount of K/kg wet weight has been estimated from two types of muscle cells, white cells from the breast muscle and red cells from the thigh muscle, assuming that these types of cells represent about 90% or more of all cells in the body.

(2) Cell tissue mass is the cell mass plus extracellular fluid.

(3) Cell mass has been calculated from cell tissues assuming that 15% to 20% of the volume of the cell is extracellular fluid (Elkinton and Danowski, 1955 and Draper, 1968).

$$\therefore \text{ cell tissue mass } = \frac{42.3 \times 1000}{91.9} = 460.0 \text{ grams}$$

If about 15% of the volume of the cell tissue is occupied by extracellular fluid (Draper, 1968), this will give a cell mass of 391.0 g.

Table 11 gives the amount of magnesium present in the bone mass, in the total body and in the cells of the fowl at different ages. The method used to calculate the cell mass on the magnesium basis is similar to that used to calculate potassium. Although nearly half the magnesium content of the body is in the bone mass, one is still able to calculate cell mass from this cation. The results obtained for the estimated cell mass, both on the potassium basis and the magnesium basis, are in remarkable agreement. Table 12 presents the estimated cell mass from magnesium and the proportion of cell mass to the live weight of the fowl at different ages. Cell mass can also be calculated by a different method to the one mentioned above. In the case of the domestic fowl cell mass can be estimated according to the following calculation:

$$CM = WB - (Wr + Wz + Wf + We + Wn)$$

where CM = cell mass, WB = body weight, Wr = feather weight, Wz = gizzard and crop content weight, Wf = fat mass, We = extracellular fluid, Wn = bone mass.

Table 13 gives the cell mass as has been calculated according to this formula. In this table the bone mass is

TABLE 11

Calculation of cell Mg from total body Mg

Values given for Mg are in millimoles

Age (weeks)	Live weight (g)	(1) Fresh bone weight (g)	(2) Mg available in bones	Mg in the total body	(3) Mg available in cell tissue
8	725 ± 23.1	66 ± 1.6	4.2 ± 0.26	9.7 ± 0.5	5.5 ± 0.25
12	1016 ± 23.0	66 ± 1.1	4.2 ± 0.11	11.8 ± 1.2	7.6 ± 0.12
16	1140 ± 30.8	86 ± 0.1	5.4 ± 0.28	13.1 ± 1.1	7.6 ± 0.16
18	1252 ± 40.6	76 ± 0.1	4.8 ± 0.32	13.2 ± 1.3	8.3 ± 0.14
19	1366 ± 68.0	93 ± 0.8	5.9 ± 0.25	14.7 ± 1.8	8.8 ± 0.26
20	1459 ± 79.6	111 ± 2.1	7.0 ± 0.30	15.3 ± 0.9	8.3 ± 0.19
21	1484 ± 51.2	97 ± 0.9	6.1 ± 0.11	15.0 ± 1.2	8.9 ± 0.15
22	1530 ± 64.9	116 ± 1.9	7.4 ± 0.21	16.9 ± 2.0	9.6 ± 0.28
23	1548 ± 51.8	121 ± 2.4	7.7 ± 0.10	15.8 ± 1.9	8.1 ± 0.26
24	1381 ± 31.0	104 ± 1.4	6.6 ± 0.15	13.5 ± 2.1	6.9 ± 0.13
26	1514 ± 53.0	100 ± 0.8	6.3 ± 0.28	14.6 ± 2.1	8.3 ± 0.17
28	1588 ± 67.9	142 ± 1.2	9.0 ± 0.32	16.5 ± 1.2	7.8 ± 0.19
30	1514 ± 40.0	132 ± 1.7	8.3 ± 0.30	16.7 ± 2.1	7.5 ± 0.18
76	2053 ± 41.0	153 ± 0.8	9.7 ± 0.29	19.9 ± 3.0	10.2 ± 0.16

Values given are means of six birds (± SEM)

(1) Fresh bone mass has been estimated from direct bone analysis where about 11.5% of the fresh bone is Ca.

(2) Bone Mg has also been estimated from direct bone analysis where about 0.152% of the fresh bone is Mg.

(3) The amount of Mg available in cell tissues has been calculated from the total Mg in the body less that of the bones.

TABLE 12

Calculation of cell mass from cell tissues on Mg basis

Values given for Mg are in millimoles

Age (weeks)	(1) Amount of Mg in the cell tissue	(2) Amount of Mg/Kg wet weight	(3) Cell tissue mass (g)	(4) Cell mass (g)	Live weight (g)	Proportion of cell mass of the live weight (%)
8	5.5 ± 0.25	11.8 ± 0.25	467 ± 22.0	397 ± 6.2	725 ± 23.1	54.8 ± 1.2
12	7.6 ± 0.12	12.3 ± 0.36	617 ± 24.1	524 ± 4.3	1016 ± 23.0	51.6 ± 1.1
16	7.6 ± 0.16	11.5 ± 0.15	659 ± 19.3	560 ± 3.8	1140 ± 30.0	49.2 ± 1.9
18	8.4 ± 0.14	12.0 ± 0.31	698 ± 19.2	593 ± 8.1	1252 ± 40.6	47.4 ± 1.8
19	8.8 ± 0.26	11.5 ± 0.13	767 ± 11.1	652 ± 11.1	1366 ± 68.0	47.8 ± 1.3
20	8.3 ± 0.19	11.1 ± 0.23	747 ± 31.3	635 ± 12.1	1469 ± 79.6	43.2 ± 0.9
21	8.9 ± 0.15	11.6 ± 0.12	767 ± 29.0	652 ± 14.2	1484 ± 51.2	43.9 ± 2.1
22	9.6 ± 0.28	11.6 ± 0.11	823 ± 18.0	700 ± 9.8	1530 ± 64.9	45.7 ± 1.8
23	8.1 ± 0.26	11.3 ± 0.19	715 ± 19.8	601 ± 8.1	1548 ± 51.8	39.3 ± 1.2
24	6.9 ± 0.13	11.6 ± 0.18	598 ± 20.2	509 ± 10.2	1381 ± 31.0	37.0 ± 0.7
26	8.3 ± 0.17	11.5 ± 0.17	717 ± 31.2	610 ± 12.1	1514 ± 53.0	40.3 ± 2.1
28	7.9 ± 0.19	10.5 ± 0.10	759 ± 15.0	645 ± 14.2	1588 ± 67.9	40.6 ± 2.5
30	8.3 ± 0.18	11.1 ± 0.21	750 ± 21.0	638 ± 10.2	1514 ± 40.0	42.1 ± 1.9
76	10.2 ± 0.16	11.1 ± 0.27	915 ± 38.0	777 ± 36.1	2053 ± 41.0	38.0 ± 2.0

Values given are means of six birds (± SEM)

(1) The amount of Mg in the cells has been calculated from the total Mg in the body less the Mg in the bones. (There is about 0.152% of Mg in fresh bone).

(2) The amount of Mg/Kg wet weight has been estimated from two types of muscle cells, white cells from the breast muscle and red cells from the thigh muscle, assuming that these types of cells represent about 90% or more of all cells in the body.

(3) Cell tissue mass is the cell mass plus extracellular fluid.

(4) Cell mass is the cell tissue mass less the extracellular fluid which is about 15% to 20%.

TABLE 13

Calculation of cell mass as the total body weight less the sum of the weights of the feathers, fat mass, extracellular fluid (E.C.F.) bone mass and the crop and gizzard contents. (E.C.F. has been calculated on the basis of the K contents)

Values given below are in grams

Age (weeks)	Feather weight	Fat mass	Extracellular fluid	Bone mass* and fat water free	Crop and gizzard contents	Cell mass	Live weight	Proportion of cell mass to live wt. (%)
8	85	54 ± 3.3	130	33.4	10.0	413	725 ± 23.1	56.8
12	100	84 ± 4.1	237	36.4	14.0	545	1016 ± 23.0	53.5
16	110	125 ± 7.3	239	47.6	14.0	604	1140 ± 30.8	53.0
18	125	155 ± 19.6	260	42.0	18.0	651	1252 ± 40.6	52.0
19	140	186 ± 20.1	253	51.1	18.0	717	1366 ± 68.0	52.2
20	145	255 ± 22.1	276	60.7	18.5	713	1469 ± 79.6	48.5
21	160	253 ± 11.3	271	53.3	20.5	727	1484 ± 51.2	48.9
22	185	212 ± 16.4	270	63.9	23.5	736	1530 ± 64.9	48.1
23	180	240 ± 18.1	302	66.9	25.0	725	1548 ± 51.8	46.8
24	170	203 ± 19.2	280	57.2	28.0	642	1381 ± 31.0	46.5
26	195	240 ± 14.8	307	54.8	28.0	688	1514 ± 53.0	45.5
28	205	227 ± 9.5	284	78.1	32.0	762	1588 ± 67.9	47.9
30	200	204 ± 12.8	284	71.4	32.0	723	1514 ± 40.0	47.7
76	245	497 ± 22.9	392	84.2	35.0	799	2053 ± 41.0	39.0

Values given are means of six birds (± SEM)

* Bone mass is estimated on the basis that chicken fresh bone contains approximately 15% fat and 30% water.

calculated from direct bone analysis of an adult chicken where approximately 11.5%* of the fresh bone mass is calcium (see Table 33 p. 106). Correction for bone fat and water has been considered in these calculations. Extracellular fluid has been estimated from the potassium results. Table 14 gives the estimated extracellular fluid by using the potassium content where intracellular fluid has been calculated and deducted from the total water content. Potassium concentration per litre of intracellular fluid was estimated from the total water content of the body cells where about 15% to 20% of water lying outside the cells was considered, and from the proportion of potassium per kilogram wet weight of muscle cells. The feather content, fat mass, crop and gizzard were all recorded. By subtracting the sum of all these components from the live body weight, the cell mass can be determined as it is the only remaining component. Cell mass calculated in this way gives a different result from the method used to calculate cell mass in Table 12. The method used in Table 13 shows higher results than the estimations shown in Table 12. An explanation for this might be that not all potassium is an intracellular ion as had been assumed in the calculation. The higher results obtained for the cell mass were those which were calculated on the sodium basis (see Table 15 p. 72). On that basis the cell mass was estimated exactly in the same way as that used in Table 13. The only difference is that extracellular fluid was ob-

* For the birds aged 8 and 12 weeks this percentage is purely an assumption.

TABLE 14

Calculation of the extracellular fluid (E.C.F.) from the potassium content of the body

Age (weeks)	K mM/litre	K contents (mM)	Total water content	Intracellular fluid (I.C.F.)	Extracellular fluid (E.C.F.)
8	143 ± 4.6	42.3 ± 1.4	424 ± 21.6	294	130
12	163 ± 3.8	59.5 ± 1.2	601 ± 18.2	363	237
16	163 ± 6.1	65.5 ± 1.8	640 ± 23.2	402	238
18	152 ± 2.1	65.9 ± 2.1	693 ± 28.1	433	360
19	156 ± 4.2	74.4 ± 1.8	731 ± 22.7	478	253
20	148 ± 4.7	70.6 ± 2.7	753 ± 29.5	477	276
21	151 ± 9.0	70.0 ± 3.1	734 ± 30.1	463	271
22	155 ± 8.1	77.9 ± 2.9	770 ± 21.1	500	270
23	160 ± 11.5	72.1 ± 2.5	751 ± 11.5	448	302
24	152 ± 5.8	62.1 ± 1.5	688 ± 12.5	407	280
26	155 ± 5.6	68.8 ± 1.1	751 ± 22.6	443	307
28	148 ± 3.2	72.3 ± 2.0	772 ± 24.5	488	284
30	154 ± 2.2	74.6 ± 1.9	768 ± 18.1	483	284
76	150 ± 5.1	83.3 ± 2.6	944 ± 36.1	553	391

Values are means of six birds (± SEM)

tained from the sodium content of the body based on the concentration of sodium as 168 mM/litre of water (El-Jack and Lake, 1967). Table 15 gives the calculated cell mass and its proportion to the body weight using the sodium ion to estimate the extracellular fluid. The reason why higher results were obtained by this method and not the other methods is probably related to the assumption that the sodium ion is mainly an extracellular ion and very little of it is inside the cells. Fig. 23 shows the calculated cell mass as has been estimated by potassium, magnesium and sodium. The calculated cell mass based on the potassium and magnesium ions are in better agreement than the one based on the sodium ion. Because of the different methods used in the literature for measuring the extracellular space, and because of the different answers provided in reply to this question (Elkinton and Danowski, 1955), the belief that sodium is a dominant ion of the extracellular fluid and very little of it exists within the cells may not be true and further investigation is essential. Widdowson (1969) stated that in the 14 week old human foetus the chloride space is two-thirds of the total water, suggesting that about two-thirds of the water in the skeletal muscle at this age is outside the cells. By the time of full-term birth, the extracellular water is already less than half the total, and in the adult less than a quarter of the water in the muscle is in the extracellular phase. The author found that the sodium space

TABLE 15

Calculation of cell mass as the total body weight less the sum of the weights of the feathers, fat mass, extracellular fluid (E.C.F.) bone mass and the crop and gizzard contents. (E.C.F. has been calculated on the basis of the Na content)

Values given below are in grams

Age (weeks)	Feather weight	Fat mass	Extracellular fluid	Bone mass	Crop and gizzard contents	Cell mass	Live weight	Proportion of cell mass to live wt. (%)
8	85	54 ± 3.3	138	33.4	10.0	405	725 ± 23.1	55.8
12	100	84 ± 4.1	168	36.4	14.0	614	1016 ± 23.0	60.4
16	110	125 ± 7.3	197	47.1	14.0	647	1140 ± 30.8	56.7
18	125	155 ± 19.6	200	42.0	18.0	712	1252 ± 40.6	56.8
19	140	186 ± 20.1	203	51.1	18.0	768	1366 ± 68.0	56.2
20	145	255 ± 21.1	211	60.7	18.5	779	1469 ± 79.6	53.0
21	160	253 ± 11.3	214	53.2	20.5	784	1484 ± 51.2	52.7
22	185	212 ± 16.4	241	63.9	23.5	805	1530 ± 64.9	52.6
23	180	240 ± 18.1	198	66.9	25.0	838	1548 ± 51.8	54.1
24	170	203 ± 19.2	190	57.2	28.0	733	1381 ± 31.0	53.0
26	195	240 ± 14.8	194	54.8	28.0	802	1514 ± 53.0	52.9
28	205	227 ± 9.5	226	78.1	32.0	820	1588 ± 67.9	51.6
30	200	204 ± 12.8	241	71.4	32.0	766	1514 ± 40.0	50.6
76	245	497 ± 22.8	281	84.2	35.0	911	2053 ± 41.0	44.3

Values given are means of six birds (± SEM)

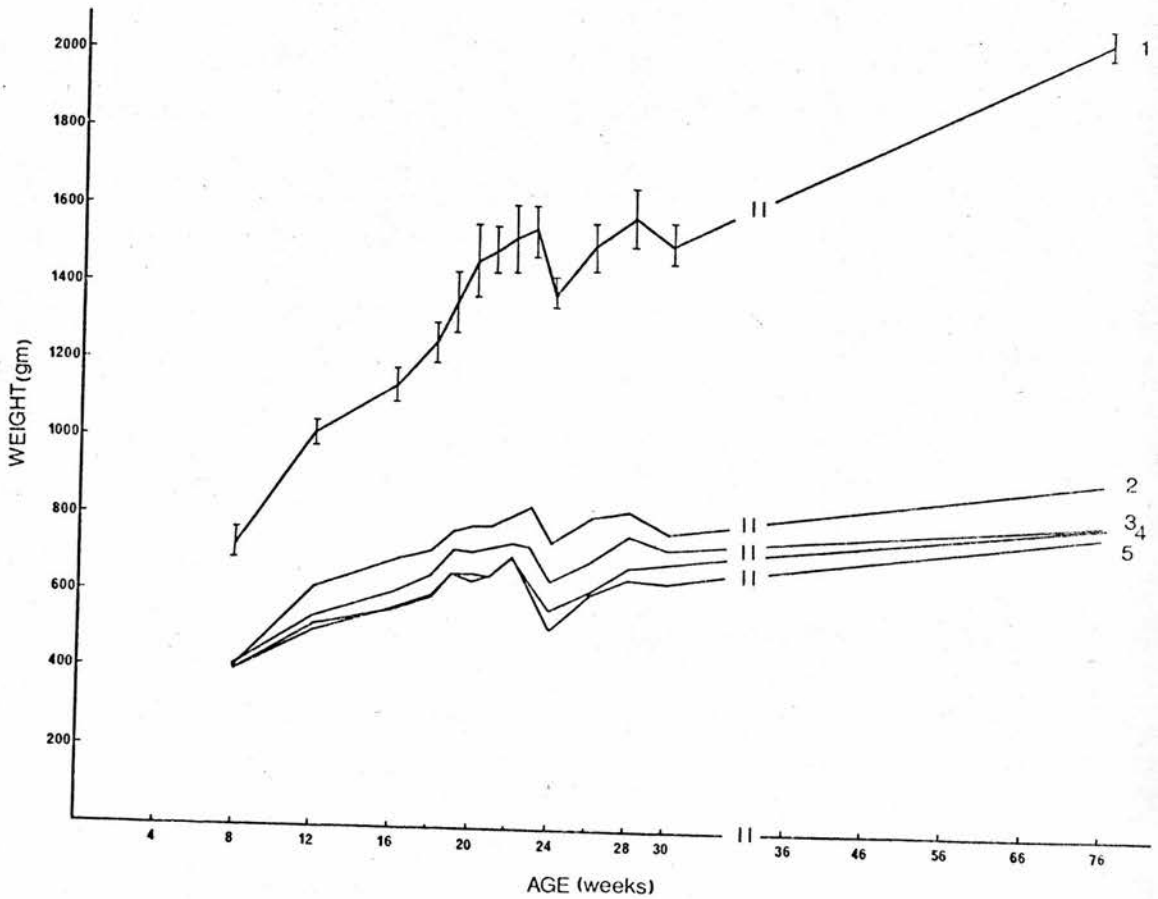

FIG. 23 Live weight and Calculated Cell Mass. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Live weight. 2. Cell mass calculated from Na
3. " " " " K*
4. " " " " K
5. " " " " Mg

* In this case the calculation is based on the E.C.F. which is estimated from the K contents of the body.

was larger than the chloride space which means that there is some sodium in the muscle cells.

In the present work the total water content of the skeletal muscle has been estimated both in young and old birds. Sodium content was also estimated by direct chemical analysis at different ages of the bird. From the sodium concentration stated in the literature, the amount of extracellular fluid in the younger and older bird, calculated from that concentration, was suspiciously high. The opinion, therefore, is that a considerable amount of sodium does exist inside the cells. From this argument it would seem that estimations based on potassium to determine the cell mass are more likely to be close to reality.

It was felt that the relationship between the chemical anatomy of liver growth and body growth could be of interest and this has in fact produced two points of considerable interest both related to the peculiar physiology of the bird. Table 16 gives the liver analysis for total solids, protein, fat and the minerals, potassium, sodium, magnesium and calcium. The mean liver wet weight of the young chick (4 weeks old) was 11.3 g with a coefficient of variation of 14.3% This weight rose to 86.8 g at the age of 76 weeks with a large coefficient of variation of 52.6%. The increase in the liver weight is parallel to that of the live body weight (Fig. 3). The contribution of the liver weight to the body weight is approximately 3.2% in the young bird and 2.5% in

TABLE 16

Liver wet weight, total solids, protein and fat contents

Values given below are in grams

Age (weeks)	Wet weight	Coefficient of variation	Total solids	Protein	Fat	Δ solids	Protein/kg w. wt.	Fat/kg w. wt.
4	11.3 ± 0.7	14.3	2.6 ± 0.1	1.8 ± 0.10	0.4 ± 0.02	0.4 ± 0.02	164	39
6	18.4 ± 0.8	11.3	4.5 ± 0.3	3.1 ± 0.20	0.6 ± 0.02	0.8 ± 0.07	166	33
8	26.5 ± 0.8	7.6	6.3 ± 0.3	4.4 ± 0.20	0.9 ± 0.05	0.9 ± 0.07	168	36
12	35.2 ± 1.3	9.4	8.6 ± 0.3	6.2 ± 0.40	1.5 ± 0.10	0.9 ± 0.06	175	43
16	39.6 ± 1.1	6.7	10.8 ± 0.3	7.2 ± 0.16	1.9 ± 0.03	1.8 ± 0.10	181	49
18	41.8 ± 3.0	17.7	12.9 ± 1.4	7.4 ± 0.65	3.4 ± 0.89	2.1 ± 0.20	178	81
19	49.4 ± 5.1	25.1	14.0 ± 1.5	7.5 ± 0.78	4.5 ± 0.65	1.9 ± 0.25	152	91
20	42.1 ± 2.5	14.4	11.3 ± 0.9	7.3 ± 0.43	3.6 ± 0.50	0.2 ± 0.09	173	88
21	53.3 ± 2.9	13.7	18.1 ± 1.5	8.1 ± 0.26	7.8 ± 1.60	2.2 ± 0.26	153	146
22	53.7 ± 5.1	23.4	16.5 ± 1.6	6.9 ± 0.74	5.8 ± 0.65	3.8 ± 0.36	130	108
23	46.4 ± 2.0	10.8	14.2 ± 0.8	6.8 ± 0.32	4.5 ± 0.66	2.9 ± 0.36	146	98
24	54.7 ± 3.5	15.5	16.5 ± 1.7	8.5 ± 0.47	5.2 ± 1.22	2.7 ± 0.48	156	96
26	53.2 ± 4.4	20.4	18.9 ± 2.3	8.7 ± 0.65	7.3 ± 1.61	2.9 ± 0.19	163	137
28	50.4 ± 4.8	23.8	15.6 ± 2.0	7.2 ± 0.45	6.6 ± 1.49	2.0 ± 0.24	143	131
30	45.7 ± 3.8	20.4	12.9 ± 1.2	7.7 ± 0.34	3.7 ± 0.84	1.5 ± 0.21	168	81
76	86.8 ± 18.7	52.6	34.5 ± 10.6	12.6 ± 1.90	13.3 ± 2.71	11.8 ± 0.82	145	154

Values are means of six birds (± SEM)

the adult bird (Table 3). In a human body weighing 65 Kg, the liver was assessed to contribute some 2.3% to the body weight (Passmore and Draper, 1970). In a male man aged 25 years, weighing 71.8 Kg (who had admittedly died of uraemia) the liver was found to contribute 3.48% to body weight (Widdowson et al, 1950). The composition of the liver of the chick changes greatly during the period of 4 to 76 weeks of age. The total solids, which were as little as 2.6 g at 4 weeks (23% of the wet weight), rose to 34.5 g at 76 weeks (40% of the wet weight). The protein content of the liver was only 1.86 g at 4 weeks (16.4%) increasing to 12.6 g at the age of 76 weeks (14.5%). However, it can be seen that the proportionate increase in fat is much higher than that of protein. It is apparent from Table 16 that the protein content has increased sixfold, whereas the fat content has increased nearly thirtyfold by 76 weeks. In other words, if one looks at the percentage of protein content of the liver on the wet weight basis, one will find that at 4 weeks of age the percentage of protein is 16.4 and that of the fat is only 3.5. The important point is that the protein percentage remains at about 14% to 16% during the period of the studies while the fat percentage increased from 3.9 to 15.4%. This is quite a significant difference in the liver composition which will indicate a link between liver and fat metabolism. This is borne out by the fact that, as liver fat increases, so does

the body fat content which increases remarkably from 7.5% at 8 weeks up to 24% at 76 weeks (Table 24). The two major reviews on the physiology of adipose tissue published in 1965 ((Renold and Cahill) and Whipple), considered in the main rat or mouse adipose tissues. The reason for that may rest on the belief that these tissues are entirely representative of adipose tissue for other mammals, and the adipose tissue is the major site of lipogenesis in the mammalian body. Recent work by Rudman et al (1966) shows that there is considerable variability between the lipogenic activity of adipose tissue from different mammalian species. In addition, the primary role of the adipose tissue in lipogenesis in the intact rat has been questioned by the findings of Hollenberg and Vost (1968) who indicated that hepatic lipogenesis may well be of primary importance in the production of fat within the intact mammal. However, recent results obtained with avian species (Evans, 1969) and the results obtained with avian liver, presented in this work, may cause attention to be redirected towards the liver as a major site of the production of fat. Table 17 gives the liver fat and the total body fat content of the domestic fowl at different ages. The increase in the liver fat is parallel to that of the total body, but the proportionate increase of the liver fat is somewhat higher than that of the total body. The liver fat increases from 35.7 g/Kg wet weight at 8 weeks of age up to 154 g/Kg wet weight at 76 weeks, corresponding to an increase of approximately 300%.

TABLE 17

Liver fat and total body fat in layer type hens
Values are means of six birds (± SEM)

Age (weeks)	Liver fat (g/kg w. wt.)	Total body fat (g/kg w. wt.)
8	36 ± 1.3	86 ± 4.9
12	43 ± 1.6	88 ± 4.2
16	49 ± 1.3	126 ± 4.8
18	81 ± 14.8	147 ± 17.5
19	90 ± 9.1	157 ± 9.8
20	90 ± 2.4	200 ± 9.4
21	146 ± 24.0	204 ± 5.6
22	107 ± 6.2	166 ± 10.6
23	97 ± 14.9	183 ± 11.8
24	95 ± 18.8	182 ± 13.3
26	134 ± 21.5	195 ± 12.3
28	131 ± 22.5	175 ± 3.5
30	78 ± 13.3	161 ± 10.9
76	154 ± 34.6	278 ± 10.4

The total body fat increases from 86 g at 8 weeks up to 278 g/Kg wet weight, corresponding to an increase of about 222%. This is further illustrated by Fig. 24 where it can be seen that there is a striking parallelism between liver fat and body fat composition including the physiological vicissitudes associated with the initiation of egg laying. Taking the whole population of birds analysed (n = 84), the correlation coefficient is 0.643 which is highly significant ($P < 0.001$). Fig. 25 gives the scatter diagram of Fig. 24 which further illustrates this point. ~~This correlation suggests that a liver biopsy could be a sufficient measure of the fat level of the body~~. The large coefficient of variation at 76 weeks of age, even when n = 6 (52.6%), suggests a big difference in efficiency of lipid metabolism which might have practical genetic significance. The mineral content of the liver is given in Table 18. The proportion of these four principal elements given in this table does change significantly between the young and the old bird, particularly concerning sodium and calcium. The calcium proportion increases as the fowl approaches sexual maturation. From approximately the 20th week of age the proportion of calcium in the liver rises to a higher level than before. This increase in calcium level may be related to the transport of protein destined to become yolk proteins (Winget and Smith, 1958). Since yolk proteins have calcium bound with them, calcium therefore becomes an integral part of these proteins and is essential to their formation

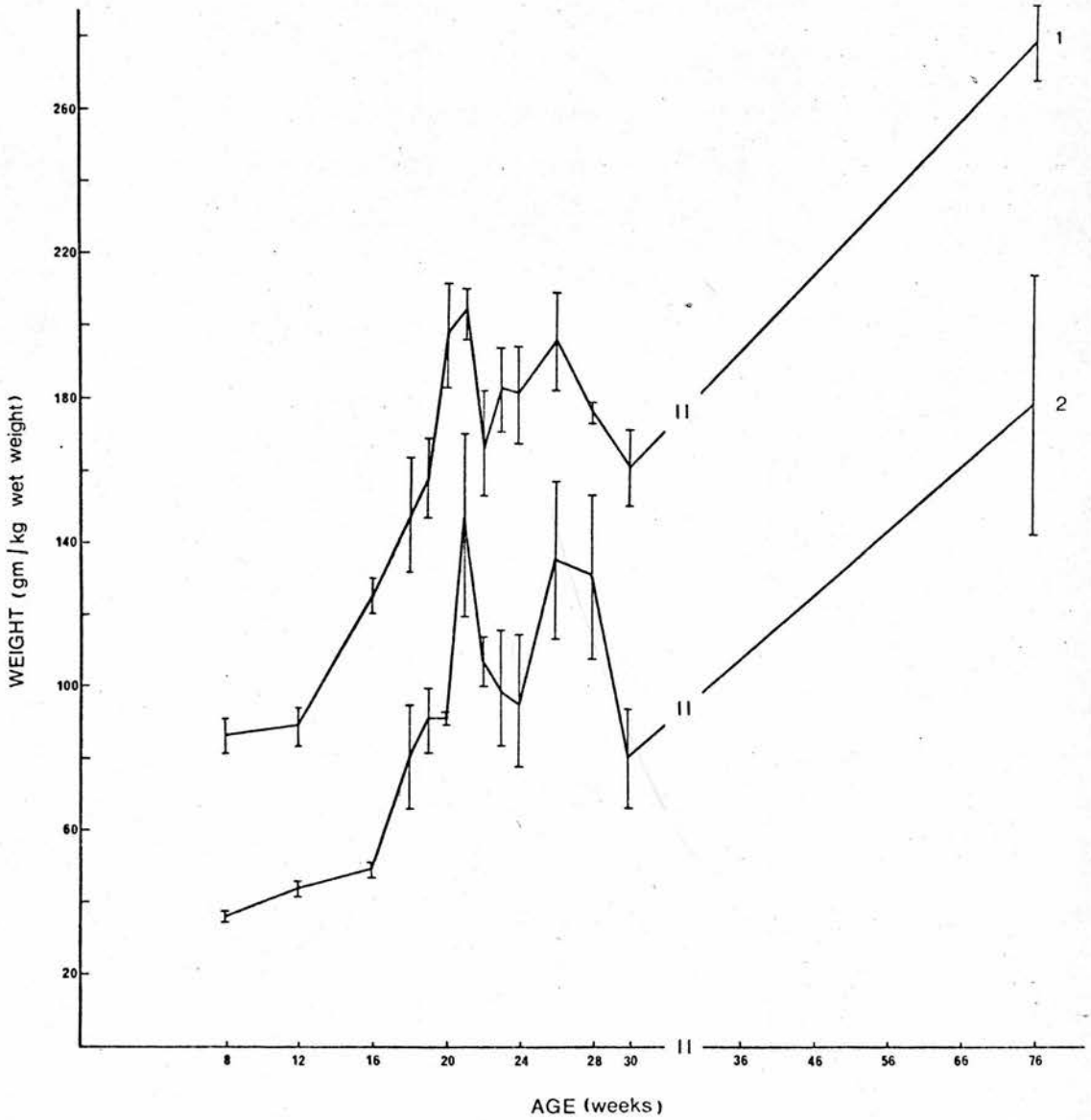

FIG. 24 Body and liver fat changes in layer type hens. Values are mean ± SEM. For each point n = 6 ♂♂. 1. Body fat. 2. Liver fat.

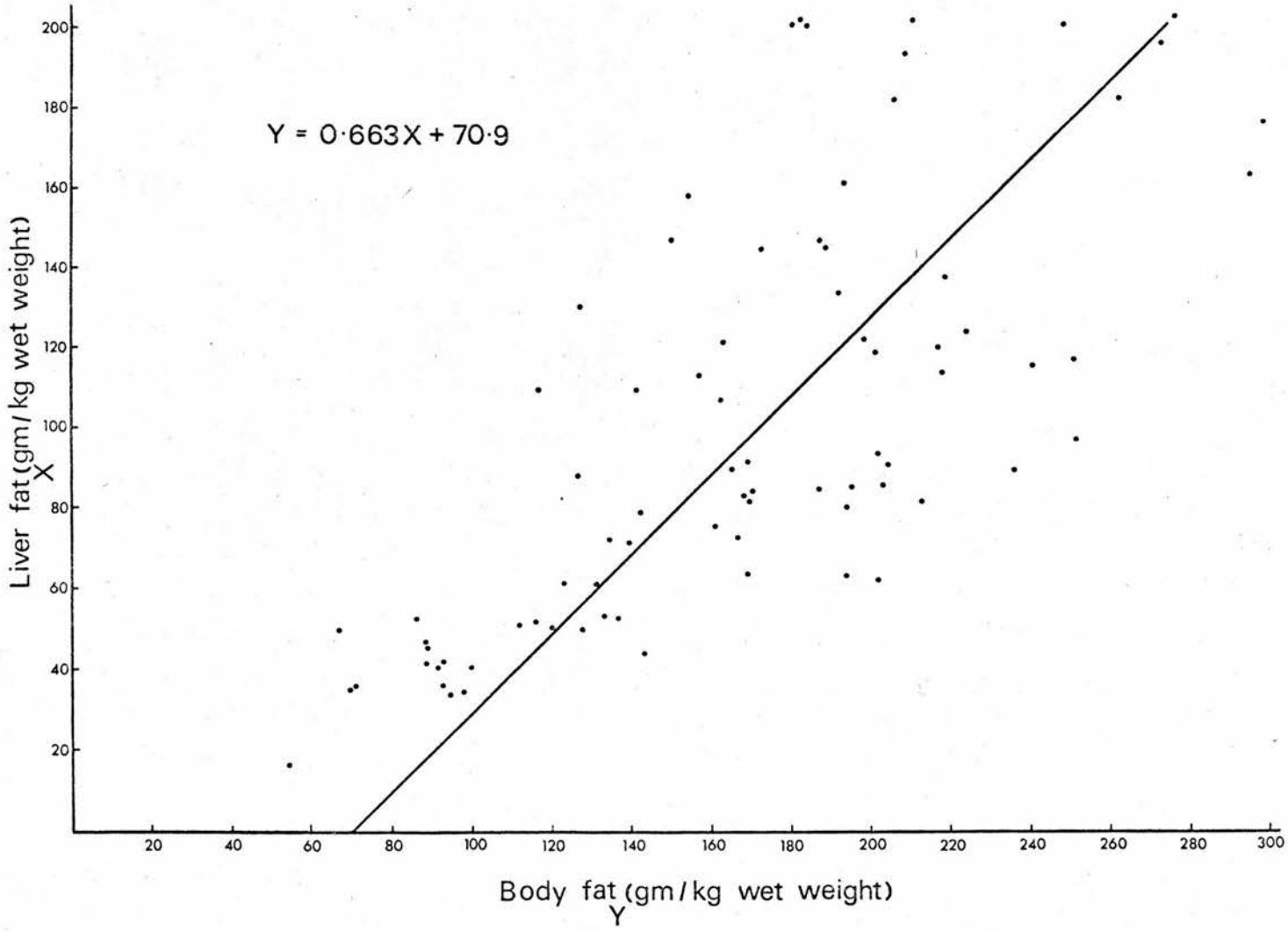

FIG. 25 Scatter diagram relating liver fat and total body fat in layer type hen.

TABLE 18

Liver mineral contents (potassium, sodium, magnesium and calcium)
Values given below are in mM/Kg wet weight

Age (weeks)	Potassium	Sodium	Magnesium	Calcium
4	64.4 ± 1.0	55.4 ± 0.5	6.8 ± 0.12	0.8 ± 0.01
6	62.7 ± 1.9	65.5 ± 0.6	7.4 ± 0.23	1.4 ± 0.02
8	60.8 ± 2.8	67.4 ± 2.2	7.1 ± 0.29	1.2 ± 0.04
12	66.3 ± 2.3	58.5 ± 2.8	7.4 ± 0.21	1.1 ± 0.08
16	64.7 ± 1.8	63.1 ± 2.8	7.1 ± 0.17	1.1 ± 0.03
18	61.0 ± 2.7	63.3 ± 4.1	6.6 ± 0.24	1.1 ± 0.10
19	60.5 ± 2.3	61.9 ± 7.7	6.4 ± 0.28	1.2 ± 0.06
20	53.9 ± 2.0	67.8 ± 1.9	6.9 ± 0.17	1.4 ± 0.08
21	55.6 ± 3.9	36.7 ± 2.0	6.6 ± 0.30	1.7 ± 0.23
22	55.1 ± 0.8	47.0 ± 2.9	5.9 ± 0.11	1.4 ± 0.27
23	62.4 ± 3.4	37.0 ± 1.4	6.7 ± 0.31	1.3 ± 0.09
24	61.2 ± 5.3	40.0 ± 2.5	6.7 ± 0.62	1.5 ± 0.18
26	61.2 ± 6.0	45.6 ± 4.4	6.3 ± 0.73	2.0 ± 0.82
28	58.2 ± 3.5	42.0 ± 2.2	5.8 ± 0.19	1.6 ± 0.14
30	60.2 ± 3.7	48.9 ± 3.9	7.0 ± 0.38	1.8 ± 0.16
76	58.9 ± 3.8	41.4 ± 4.3	6.9 ± 0.37	2.0 ± 0.16

Values are means of six birds (± SEM)

(Bailey, 1957). It can be seen in Table 19 that the liver protein content changes little but the liver protein/calcium ratio changes from 188 to 75. There is an absolute increase in the calcium in the liver which is presumably bound to some proteins at the stage of development of first egg formation at 20 to 21 weeks. The protein/Mg and protein/K ratios do not appear to vary significantly during growth. From the period of 20 weeks onwards there is some decline in sodium content. Fat also increases sharply at this time, possibly for the formation of yolk fat or, more likely, as a result of overeating and subsequent increase in fat deposition.

In the previous studies the results were concerned mainly with the components of the bird. After dissection, the various constituents of the bird, such as skeletal muscle and carcass, were separated and each of these tissues analysed individually. In this section these results will be dealt with together treating the bird as a whole. Producing results of this kind can be interesting and valuable as they form a reference for the total body composition of the fowl during growth and development.

Table 20 shows the composition of the bird in terms of the skeletal muscle and the body carcass from 8 weeks up to 76 weeks of age. Using this table one can measure the amount of material not accounted for during chemical analysis, such as the feathers, crop and gizzard contents and some water

TABLE 19

Liver protein/mineral ratios of the fowl at different ages

Values for protein are g/Kg wet weight
Values for minerals are mM/Kg wet weight

Age (weeks)	Protein (g/kg w. wt.)	K (mM/kg w. wt.)	Protein/K	Mg (mM/kg w. wt.)	Protein/Mg	Ca (mM/kg w. wt.)	Protein/Ca
4	164	64.4	2.5	6.8	23.8	0.8	188
6	166	62.7	2.7	7.4	22.4	1.4	117
8	168	60.8	2.8	7.1	23.8	1.3	132
12	175	66.3	2.6	7.4	23.5	1.1	165
16	181	64.7	2.8	7.1	25.5	1.1	167
18	178	61.0	2.9	6.6	26.9	1.1	160
19	152	60.5	2.5	6.4	23.7	1.2	130
20	173	53.8	3.2	6.9	24.8	1.4	122
21	153	55.6	2.7	6.6	23.1	1.7	89
22	130	55.1	2.3	5.9	21.8	1.3	95
23	145	62.4	2.3	6.7	21.9	1.3	108
24	155	61.2	2.5	6.7	23.2	1.5	99
26	163	61.2	2.6	6.3	26.1	2.0	82
28	142	58.2	2.4	5.8	24.7	1.6	86
30	168	60.2	2.8	7.0	23.9	1.9	94
76	153	58.9	2.6	6.9	22.0	2.0	75

TABLE 20

Breast muscle, thigh muscle and the total body carcass wet weight of the fowl at different ages

Values given below are in grams

Age (weeks)	Live wt.	Muscle wt. Breast	Muscle wt. Thigh	Body carcass wt.	Total body carcass wt.	(1) Difference from live wt.
8	725	83	48	503	634	91
12	1016	124	76	689	889	127
16	1140	141	91	758	990	150
18	1252	154	101	834	1089	163
19	1366	187	115	879	1181	185
20	1469	192	114	968	1274	195
21	1484	172	108	975	1255	229
22	1531	185	114	979	1278	253
23	1548	194	116	969	1279	269
24	1381	164	100	871	1135	246
26	1514	186	118	946	1240	274
28	1588	190	117	988	1295	293
30	1514	183	119	961	1263	251
76	2053	240	138	1408	1786	267

Values are means of six birds

(1) Difference between live weight and total body carcass weight = feathers + some water + gizzard and crop contents.

which may have been lost during dissection. The total of such material is given in Table 20 as the difference between the live body weight and the total body carcass. Table 21 gives the composition of the bird in terms of protein, fat and water during the different ages of the animal. It also gives the approximate amount of minerals which one may expect to find, and this has been estimated as being the difference between the calculated carcass weight and the sum of protein, fat and water contents of the body carcass and the breast and thigh muscles. An advantage of this table is that it can enable one to compare the actual amount of minerals determined by chemical analysis with the approximate amount of minerals estimated on a calculation basis. Table 22 gives the composition of the bird in terms of minerals from the 8th week up to the 76th week of age. The amount of minerals presented in this table was estimated by direct chemical analysis of skeletal muscle and the body carcass. By the use of the XRF technique, the estimations were carried out on a fat-free basis. Calcium, phosphorus, potassium, sodium, magnesium, sulphur, chloride and iron have been estimated. The total of these minerals was taken as the major composition of the body minerals and quantitatively was considered to be the whole mineral component of the body. In this calculation, phosphorus was estimated as phosphate (PO_4) because of its existence in the body mainly in the form of calcium phosphate ($Ca_3 (PO_4)_2$). The molecular weight

TABLE 21

Protein, fat and water content of breast muscle, thigh muscle and body carcass at different ages

Values given below are in grams

Age (weeks)	(1) Total body carcass wt.	Muscle content: Breast Protein	Breast Fat	Breast Water	Thigh Protein	Thigh Fat	Thigh Water	Body carcass content: Protein	Fat	Water	(2) Total content of protein fat and water	(3) Difference between (1) and (2)
8	634	18.0	0.8	62	9.1	1.8	37.0	93	52	325	599	35
12	889	30.0	1.4	92	15.9	3.1	57.1	125	80	451	855	34
16	990	35.3	1.6	104	19.2	3.6	67.5	139	120	469	959	31
18	1089	37.5	1.7	113	20.9	3.3	75.1	149	155	504	1059	30
19	1181	45.3	2.2	138	24.2	4.6	85.5	156	179	508	1143	38
20	1274	46.2	2.1	142	24.2	4.7	83.9	154	248	527	1232	42
21	1255	42.5	2.5	125	23.6	4.7	78.8	157	246	529	1209	46
22	1278	47.3	2.3	133	24.5	5.0	83.1	165	229	553	1242	37
23	1279	49.1	2.7	140	25.3	4.6	84.9	157	242	525	1231	48
24	1135	40.0	1.7	121	21.1	3.6	73.7	138	197	492	1088	47
26	1250	46.6	1.9	136	25.7	4.6	86.4	153	233	528	1215	35
28	1295	45.7	2.9	141	25.4	4.5	86.4	163	219	544	1232	63
30	1263	46.2	2.8	133	26.7	5.3	85.8	157	195	549	1201	62
76	1786	59.4	4.4	174	29.2	8.1	99.7	194	485	668	1722	64

Values are means of six birds

(3) Equals mainly the expected total amount of minerals in the body

TABLE 22

Mineral composition of breast muscle, thigh muscle and the body carcass during different ages of the fowl

Values given below are in grams

Age (weeks)	Type of tissue	Mineral content								
		Ca	P	K	Mg	Na	S	Cl	Fe	Total*
8	Breast muscle	0.003	0.23	0.31	0.024	0.025	0.188	0.037	-	
	Thigh muscle	0.001	0.12	0.17	0.012	0.024	0.118	0.037	-	
	Body carcass	7.640	4.61	1.17	0.197	0.670	-	-	0.025	
	Total	7.643	4.96	1.65	0.233	0.719	0.306	0.074	0.025	25.8
12	Breast muscle	0.003	0.37	0.51	0.039	0.043	0.301	0.070	-	
	Thigh muscle	0.003	0.19	0.30	0.020	0.044	0.202	0.061	-	
	Body carcass	7.640	4.93	1.51	0.224	0.750	-	-	0.037	
	Total	7.646	5.49	2.32	0.283	0.837	0.503	0.131	0.037	29.5
16	Breast muscle	0.004	0.38	0.57	0.043	0.046	0.325	0.073	-	
	Thigh muscle	0.004	0.22	0.35	0.024	0.052	0.270	0.071	-	
	Body carcass	9.852	5.70	1.64	0.247	0.903	-	-	0.037	
	Total	9.860	6.30	2.56	0.314	1.001	0.595	0.144	0.037	33.7
18	Breast muscle	0.003	0.44	0.57	0.048	0.058	0.375	0.086	-	
	Thigh muscle	0.003	0.24	0.36	0.027	0.062	0.264	0.073	-	
	Body carcass	8.812	5.40	1.67	0.241	0.865	-	-	0.042	
	Total	8.818	6.08	2.61	0.317	0.986	0.639	0.159	0.042	32.1

(Cont.)

Values are means of six birds

* The total of minerals has been calculated on the basis that P exists as PO_4

Table 22 (cont.)

Age (weeks)	Type of tissue	Mineral content								
		Ca	P	K	Mg	Na	S	Cl	Fe	Total
19	Breast muscle	0.005	0.48	0.71	0.058	0.073	0.417	0.100	-	
	Thigh muscle	0.004	0.27	0.43	0.031	0.075	0.296	0.093	-	
	Body carcass	10.700	6.26	1.74	0.265	0.899	-	-	0.045	
	Total	10.709	7.01	2.90	0.354	1.047	0.713	0.193	0.045	37.4
20	Breast muscle	0.004	0.51	0.70	0.058	0.095	0.443	0.103	-	
	Thigh muscle	0.003	0.27	0.40	0.032	0.087	0.301	0.074	-	
	Body carcass	12.760	6.78	1.65	0.277	0.945	-	-	0.045	
	Total	12.767	7.56	2.75	0.368	1.127	0.744	0.177	0.045	41.1
21	Breast muscle	0.040	0.45	0.63	0.055	0.081	0.400	0.086	-	
	Thigh muscle	0.003	0.26	0.36	0.028	0.075	0.291	0.070	-	
	Body carcass	11.150	6.11	1.72	0.276	0.920	-	-	0.050	
	Total	11.193	6.82	2.71	0.359	1.076	0.691	0.156	0.050	37.1
22	Breast muscle	0.005	0.53	0.73	0.063	0.084	0.467	0.097	-	
	Thigh muscle	0.004	0.26	0.40	0.028	0.080	0.298	0.083	-	
	Body carcass	13.400	7.35	1.91	0.316	1.092	-	-	0.048	
	Total	13.409	8.14	3.04	0.407	1.256	0.765	0.180	0.048	44.0
23	Breast muscle	0.005	0.54	0.74	0.060	0.081	0.480	0.106	-	
	Thigh muscle	0.003	0.27	0.43	0.030	0.088	0.308	0.082	-	
	Body carcass	14.000	9.73	1.63	0.285	0.930	-	-	0.043	
	Total	14.008	10.54	2.81	0.375	1.099	0.788	0.188	0.043	51.5

(Cont.)

Table 22 (cont.)

Age (weeks)	Type of tissue	Mineral content								
		Ca	P	K	Mg	Na	S	Cl	Fe	Total
24	Breast muscle	0.004	0.44	0.62	0.049	0.083	0.384	0.087	-	
	Thigh muscle	0.003	0.24	0.35	0.026	0.075	0.264	0.065	-	
	Body carcass	12.000	6.21	1.44	0.250	0.865	-	-	0.035	
	Total	12.007	6.89	2.41	0.325	1.020	0.650	0.152	0.035	37.7
26	Breast muscle	0.007	0.49	0.75	0.058	0.084	0.448	0.100	-	
	Thigh muscle	0.004	0.27	0.39	0.029	0.085	0.314	0.077	-	
	Body carcass	11.500	6.11	1.53	0.264	0.858	-	-	0.046	
	Total	11.510	6.88	2.68	0.350	1.027	0.762	0.178	0.046	37.6
28	Breast muscle	0.006	0.54	0.69	0.054	0.083	0.448	0.103	-	
	Thigh muscle	0.004	0.27	0.40	0.029	0.083	0.310	0.076	-	
	Body carcass	15.720	8.10	1.72	0.312	1.100	-	-	0.043	
	Total	16.410	8.91	2.82	0.395	1.256	0.758	0.180	0.043	49.1
30	Breast muscle	0.007	0.49	0.66	0.064	0.097	0.448	0.099	-	
	Thigh muscle	0.005	0.27	0.42	0.032	0.090	0.328	0.080	-	
	Body carcass	15.200	7.60	1.81	0.299	1.110	-	-	0.041	
	Total	15.212	8.36	2.91	0.400	1.300	0.776	0.179	0.041	46.3
76	Breast muscle	0.009	0.74	0.80	0.068	0.132	0.566	0.131	-	
	Thigh muscle	0.007	0.31	0.45	0.032	0.111	0.368	0.092	-	
	Body carcass	17.650	8.72	1.99	0.321	1.272	-	-	0.045	
	Total	17.670	9.76	3.25	0.477	1.544	0.934	0.223	0.045	54.0

of PO_4 is 95 and the molecular weight of P is 31. Therefore if P is equal to 4.961 g then PO_4 is equal to 4.961 X $\frac{95}{31}$ which equals 15.20 g. By adding the remaining minerals together with PO_4 the total will be 25.80 g (see Table 22 8 weeks old group). The amount of minerals given in this table were compared with those calculated in Table 21: the comparison is set out in Table 23. The difference between the calculated minerals and the directly estimated minerals is gratifyingly small, particularly when one considers the number of substances such as carbohydrates, non-protein nitrogen and miscellaneous minerals which have not been estimated.

Table 24 shows the chemical composition of the bird and presents the four major components during the different stages of growth. The components are set out in two forms, as absolute amounts and as percentages of the body weight. The body weight is expressed as two terms, one as live weight, which represents the true live weight of the animal before dissection, and the second as the body weight, after dissection, that is, the breast muscle, the thigh muscle and the carcass which altogether are named 'total body carcass'. Table 25 shows the contribution made by different tissues of the body, that is, cell mass, skeletal mass and fat mass, to the live body weight at different ages. This table illustrates a point which has been discussed previously and represented on early graphs, that when the animal ages

TABLE 23

Comparison between the calculated amount of minerals and the actual amounts determined from direct chemical analysis

Values given below are in grams

Age (weeks)	(1) The calculated amount of minerals	(2) The actual determined amount of minerals	(3) The differences	The differences (as a percentage of the body weight)
8	35	25.8	9.2	1.27
12	34	29.5	4.5	0.44
16	31	33.7	2.7	0.24
18	30	32.1	2.1	0.17
19	38	37.4	0.6	0.10
20	42	41.1	0.9	0.60
21	46	37.1	8.9	0.59
22	37	44.0	-7.0	0.46
23	48	51.5	-3.5	0.23
24	47	37.3	9.3	0.67
26	35	37.6	-2.6	0.17
28	63	49.1	13.9	0.87
30	62	46.3	15.7	0.99
76	64	54.0	10.0	0.50

Values are means of six birds

(1) From Table 16

(2) From Table 17

(3) Discrepancies, carbohydrates, non-protein nitrogen and miscellaneous minerals

TABLE 24

The total amount and the percentage of water, protein, fat and minerals of the domestic fowl at different ages (g)

Values given are means of six birds

Age (weeks)	Water	Protein	Fat	Minerals	Live wt.	Body wt.*	% of water		% of protein		% of fat		% of minerals		Total %	
							Per L.W.	Per B.W.	Per L.W.	Per B.W.	Per L.W.	Per B.W.	Per L.W.	Per B.W.	Per L.W.	Per B.W.
8	424	121	54	25.8	725	634	58.6	66.9	16.7	19.1	7.5	8.6	3.5	4.0	86.4	98.6
12	601	171	84	29.5	1016	890	59.1	67.5	16.8	19.2	8.3	9.5	2.9	3.3	87.1	99.4
16	640	174	125	33.7	1140	991	56.2	64.6	15.3	17.6	11.0	12.7	2.9	3.4	85.4	98.3
18	693	213	155	32.1	1252	1089	55.4	62.4	17.0	19.5	12.7	14.0	2.6	2.9	88.0	99.0
19	732	225	186	37.4	1366	1181	53.6	62.0	16.5	19.1	13.6	15.8	2.7	3.1	86.4	99.7
20	753	225	255	41.1	1469	1274	51.3	59.0	15.3	17.6	17.4	20.0	2.9	3.2	86.7	99.7
21	734	223	253	37.1	1484	1255	49.5	58.5	15.0	17.8	17.0	20.2	2.5	2.9	84.1	99.4
22	770	237	212	44.0	1530	1278	50.3	60.2	15.5	18.5	15.4	16.4	2.9	3.4	84.1	98.5
23	751	232	240	51.5	1548	1279	48.5	58.7	15.0	18.2	16.1	18.7	3.3	4.0	83.0	99.5
24	688	199	203	37.7	1381	1135	49.8	60.6	14.4	17.6	14.7	18.0	2.7	3.3	82.0	99.5
26	751	226	240	37.6	1514	1251	49.6	60.0	14.9	18.0	15.8	19.1	2.5	3.0	83.0	99.9
28	772	234	227	49.1	1588	1295	48.6	59.6	14.7	18.0	14.3	17.5	3.0	3.7	81.0	98.9
30	768	230	204	46.3	1514	1263	50.7	60.8	15.2	18.2	13.4	16.2	3.0	3.6	82.3	98.8
76	944	283	497	54.0	2053	1787	46.1	53.0	13.8	15.8	24.2	27.8	2.6	3.2	86.8	99.8

* Body weight is equal to live weight less the feathers, crop content and gizzard grit

L.W. = Live weight
B.W. = Body weight

TABLE 25

Contribution of tissues to live body weight at different ages

Values given as a percentage of the body weight

Age (weeks)	Live body weight (g)	Cell mass	Fat mass	Skeletal mass
8	725	53.9	7.5	9.1
12	1016	49.1	8.3	6.5
16	1140	48.9	11.0	7.4
18	1252	47.9	12.4	6.1
19	1366	48.1	13.6	7.0
20	1469	44.6	17.4	7.6
21	1484	43.8	17.0	6.5
22	1530	45.4	15.4	7.6
23	1548	41.0	15.5	7.8
24	1381	40.7	14.7	7.6
26	1514	40.6	16.0	6.6
28	1588	42.9	15.0	9.0
30	1514	45.5	13.5	8.7
76	2053	39.0	24.4	7.6

fat rather than protein tends to dominate the growth phase and the animal becomes the victim of obesity. At the age of 8 weeks about 54% of the body weight consists of cell mass to which skeletal muscle makes the largest contribution. Forbes et al (1953) found that 40% of the total body weight of an adult human subject was contributed by the skeletal muscle. Wilmer (1940) stated that 43% of the weight of the adult man was accounted for by the skeletal muscle. When the domestic fowl reaches one and a half years of age, the proportion contributed by the cell mass to the body weight is 39%. The decrease in the cell mass is largely due to the increase in the fat mass. At the age of 8 weeks in the fowl only 7.5% of the body weight is accounted for by the fat mass. This proportion rises to 24.4% when the animal reaches 1.5 years. Skeletal mass does not significantly change in its contribution to the total body weight to the same extent as cell mass and fat mass. ~~This is perhaps because the skeleton approaches its chemical maturity earlier in life than any other body component~~.

In previous sections the chemical anatomical composition of the fowl has been studied during different ages of growth. Chemical analysis of body carcass and skeletal muscles have been estimated and discussed.

4.3. Factors affecting the chemical anatomy of the fowl

The next step in this work is to consider the factors affecting the chemical anatomy of the growing fowl from hatching

up to 1.5 years. Sexual maturity and cold "stress" are the two factors studied in this work. The reaction of the body to these different factors is reflected mainly in fat mass and muscle mass. Discussion of the effects of these factors on the body composition of the fowl is included in the following section.

4.3.1. Sexual maturity

From the results presented in the section on the chemical aspects, one may have observed a slowing down and distinct decrease in the growth rate as the bird approaches sexual maturity. The live weight, cell mass and fat mass showed an appreciable decrease by the time the bird reached the 24th week of age, (Figs. 13, 14, 15, 19 and 23: see also Tables 4, 5 and 7). This is the age when all birds involved in this experiment became sexually mature. Table 26 has been presented in order that a close study of this factor can be made. The investigation was begun when the birds were at a very early age and before there was any evidence of sexual maturity. In this study individual birds were used rather than an average of a certain number of birds. This proved to be much more meaningful because an average study might include anomalus birds which could give higher or lower results. From Table 26 one can see that the observations were begun when the birds were 16 weeks old, before the onset of sexual maturity. The live body weight, carcass weight, protein, fat, minerals, cell

TABLE 26

Study of the effect of sexual maturity on the composition of the fowl
Values given are per individual bird and are expressed in grams

Type of bird	Age Wks	Live weight	Plucked body wt.	Protein content	Fat content	Mineral content					Cell mass	Skeletal mass	Breast muscle	Thigh muscle
						Ca	PO_4	K	Mg	Na				
In lay	16	-	-	-	-	-	-	-	-	-	-	-	-	-
Not in lay		1225	1066	203	142	10.1	20.8	2.6	0.34	1.0	598	88	161	94
In lay	18	1340	1154	203	124	7.9	17.7	2.6	0.29	0.9	612	69	140	106
Not in lay		1350	1188	227	199	10.2	20.5	2.8	0.34	1.0	658	88	145	104
In lay	19	1662	1447	261	286	13.8	24.5	3.2	0.38	1.2	761	119	239	136
Not in lay		1456	1250	243	202	12.8	25.0	3.0	0.39	1.2	690	111	191	117
In lay	20	1570	1369	235	281	14.0	25.1	2.9	0.38	1.3	674	121	199	121
Not in lay		1606	1435	248	294	15.6	26.9	2.9	0.41	1.2	724	135	229	124
In lay	21	1510	1263	224	258	12.1	22.4	2.7	0.37	1.1	675	105	185	99
Not in lay		1530	1330	235	281	10.3	21.7	2.9	0.38	1.2	707	89	172	125
In lay	22	1424	1155	201	226	12.6	22.9	2.4	0.34	1.1	582	110	153	93
Not in lay		1474	1239	239	171	12.4	24.6	3.1	0.37	1.3	695	107	172	104
In lay	23	1468	1216	209	261	9.9	18.4	2.4	0.29	0.9	561	85	179	105
Not in lay		1460	1224	237	164	7.1	14.3	2.7	0.26	0.7	600	62	215	129
In lay	24	1491	1249	212	257	12.5	22.4	2.6	0.35	1.2	603	109	180	105
		1289	1025	189	158	10.6	19.6	2.1	0.28	0.9	489	92	159	95
In lay	26	1660	1325	248	274	13.2	23.5	3.0	0.38	1.2	698	115	221	128
		1273	1109	202	159	9.0	19.1	2.4	0.29	0.8	558	78	163	109
In lay	28	1800	1507	241	253	20.5	33.2	3.2	0.47	1.5	762	178	212	136
		1310	1028	178	188	12.6	21.1	2.4	0.27	0.9	589	109	142	93
In lay	30	1620	1398	254	201	16.4	27.8	3.3	0.41	1.4	771	143	200	130
		1382	1120	213	139	14.3	24.0	2.5	0.33	1.1	570	124	168	107
In lay	76	2190	1920	302	596	21.0	24.1	3.6	0.51	1.7	910	183	251	157
		1913	1703	267	474	15.6	25.9	3.0	0.37	1.3	806	136	226	124

mass, skeletal mass and the two distinguished muscles of the bird, the breast and thigh muscles, were all analysed both in birds in and out of lay. These laying and non-laying birds were taken from the same age group and were approximately the same body size. In the first bird of 16 weeks there was no evidence of sexual development. At 18 weeks of age there was only one bird in lay. This bird was compared with another bird of approximately the same size but which was not in lay and the main difference was found to be between the cell mass in each bird. The bird in lay appeared to have less cell mass than the bird not in lay. The skeletal mass was also different between these two birds and was higher in the bird not in lay. The calcium content can be considered to be a major factor contributing to these differences rather than assuming that the cause is due to the state of lay of these two birds. The skeletal mass was estimated from the calcium content. The calcium situation in this case seemed rather peculiar since hypercalcemia is unrelated to egg shell production and occurs in animals that produce eggs without calcified coverings and also in hens with inactive oviducts (Bronner, 1964; Taylor and Moore, 1956 and Campbell and Turner, 1942). The example of the bird at 18 weeks of age is applicable to the remaining birds whose results are also given in Table 26. The most striking point is that the cell mass of all birds coming into lay for the first time was less than in those birds which were not in lay. The same situation applies to the breast muscle

of most of the birds in lay which was lighter than in the birds not in lay. At the end of Table 26 when all the birds had come into lay at 24 weeks of age, the effects of sexual maturity became very clear and the results are given as a range. In Fig. 26 a detailed picture is given for each individual bird of its calcium content, oviduct development and the growth pattern compared with changes in the fat-free body weight at different ages. It is apparent from this graph that there is not one bird in any state of sexual maturity before the age of 18 weeks. At this age only one bird appears to be in lay but after 18 weeks there is an increase in the number of birds becoming sexually mature and this continued until the age of 24 weeks when all birds were in lay. Therefore, the decrease in weight and chemical composition occurring during this time of sexual maturity could be as a result of a biological factor associated with this event. The tissues of the body which seem to be affected more than others are the fat mass and the muscle mass. Among the skeletal muscles, the breast muscle is affected to a far greater extent than the thigh muscle. Differential changes in these tissues will become more obvious when, in the next section, the question of cold "stress" is discussed.

4.3.2. Cold "stress"

The second factor involved in the chemical composition of the body has been studied in a separate experiment other

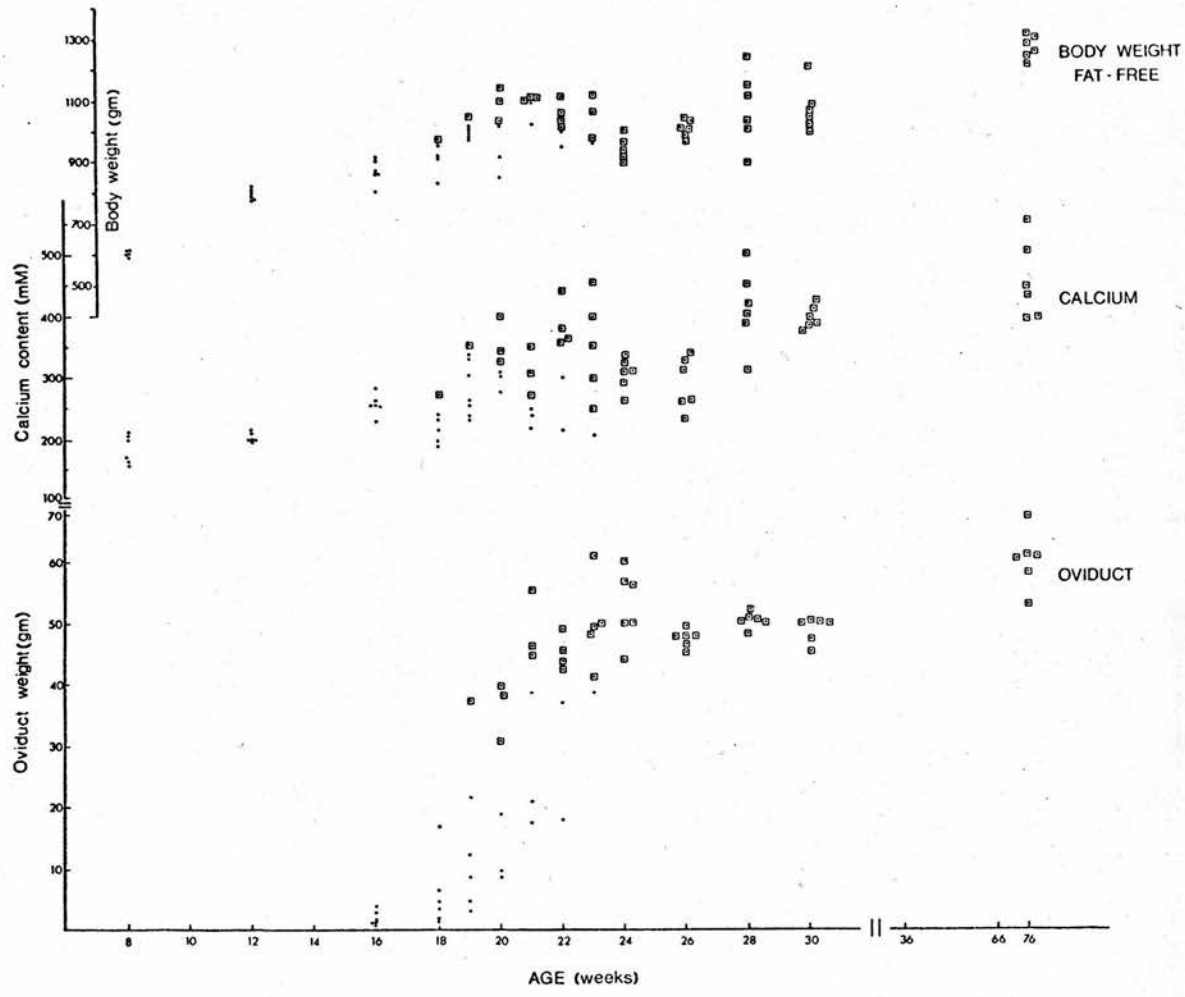

FIG. 26 Oviduct weight and calcium contents of carcase of individual body weight for each bird. The presence of an egg in the oviduct is indicated by the symbol ⊖.

than those mentioned under the headings of Anatomical and Chemical aspects. The factor itself is the effect of a cold environment on the growth of the fowl. The birds used in this experiment were commercial broiler type birds which would grow to killing weight (1.6 Kg) in 56 days. The details of this experiment have been set out on page 34. The essential point is that the test birds were chilled for 4 hours at 10°C after removal from the incubator.

Table 27 gives the live weight, the weights of the breast and thigh muscles of one side of the bird and the dissected body carcass weight for both groups, the control and experimental. From this table one can observe differences between these two groups of birds as a result of cold effect. The live weight of the control group is higher than that of the experimental group. Breast and thigh muscles were also affected by cold and were heavier in weight in the control group and lighter in the experimental group, as shown in Fig. 27. Fig. 28 shows the live weight of both groups from the first day of hatching up to 2 weeks of age. It also illustrates the range of live weight from the mean and it shows the dramatic difference between these two groups. The effect of cold on the total body weight was quite severe within these 14 days of life. The poorest of the control birds was very close in weight to the best of the experimental birds and sometimes higher. By the end of 9 days the poorest weight in the control group dominated the best weight in the experimental group.

TABLE 27

Live weight, breast and thigh muscle weight and body carcass weight of control and experimental groups

Values given below are in grams

Age (days)	(1) Live weight	Half breast	Half thigh	(2) Body carcass weight	(3) Total body weight	(4) Difference between (1) and (3)
Control group						
1	45 ± 1.0	0.4 ± 0.02	1.2 ± 0.05	39.6 ± 1.4	41.2 ± 1.4	3.8 ± 0.78
2	48 ± 1.1	0.4 ± 0.02	1.2 ± 0.04	41.5 ± 1.2	43.1 ± 1.2	4.9 ± 0.55
5	67 ± 1.4	1.1 ± 0.03	1.6 ± 0.04	60.1 ± 1.3	62.8 ± 1.3	4.2 ± 0.26
9	101 ± 3.4	2.9 ± 0.16	2.7 ± 0.12	87.3 ± 3.8	92.9 ± 4.0	8.1 ± 0.25
14	161 ± 6.8	6.3 ± 0.39	4.9 ± 0.27	145.6 ± 6.1	156.8 ± 6.7	4.2 ± 0.59
Experimental group						
2	44 ± 0.9	0.4 ± 0.02	1.2 ± 0.04	37.5 ± 0.7	39.1 ± 0.7	4.9 ± 0.32
5	59 ± 1.3	0.8 ± 0.05	1.8 ± 0.07	55.2 ± 1.4	57.8 ± 1.5	1.2 ± 0.57
9	74 ± 2.1	1.2 ± 0.07	1.5 ± 0.06	61.6 ± 1.7	64.3 ± 1.8	9.7 ± 0.56
14	104 ± 2.8	2.7 ± 0.12	2.2 ± 0.06	86.8 ± 1.8	91.7 ± 1.9	12.3 ± 1.52

Values are means of twelve birds (± SEM)

(2) Body carcass is equal to the live weight minus half breast and half thigh, yolk sac, some fluid, gizzard and crop content.

(3) The total body weight is the body carcass plus the weight of half the breast and half the thigh muscles.

(4) The difference between the live weight and the total body weight is the weight of the yolk sac, some fluid lost during dissection and the contents of the gizzard and crop (if any).

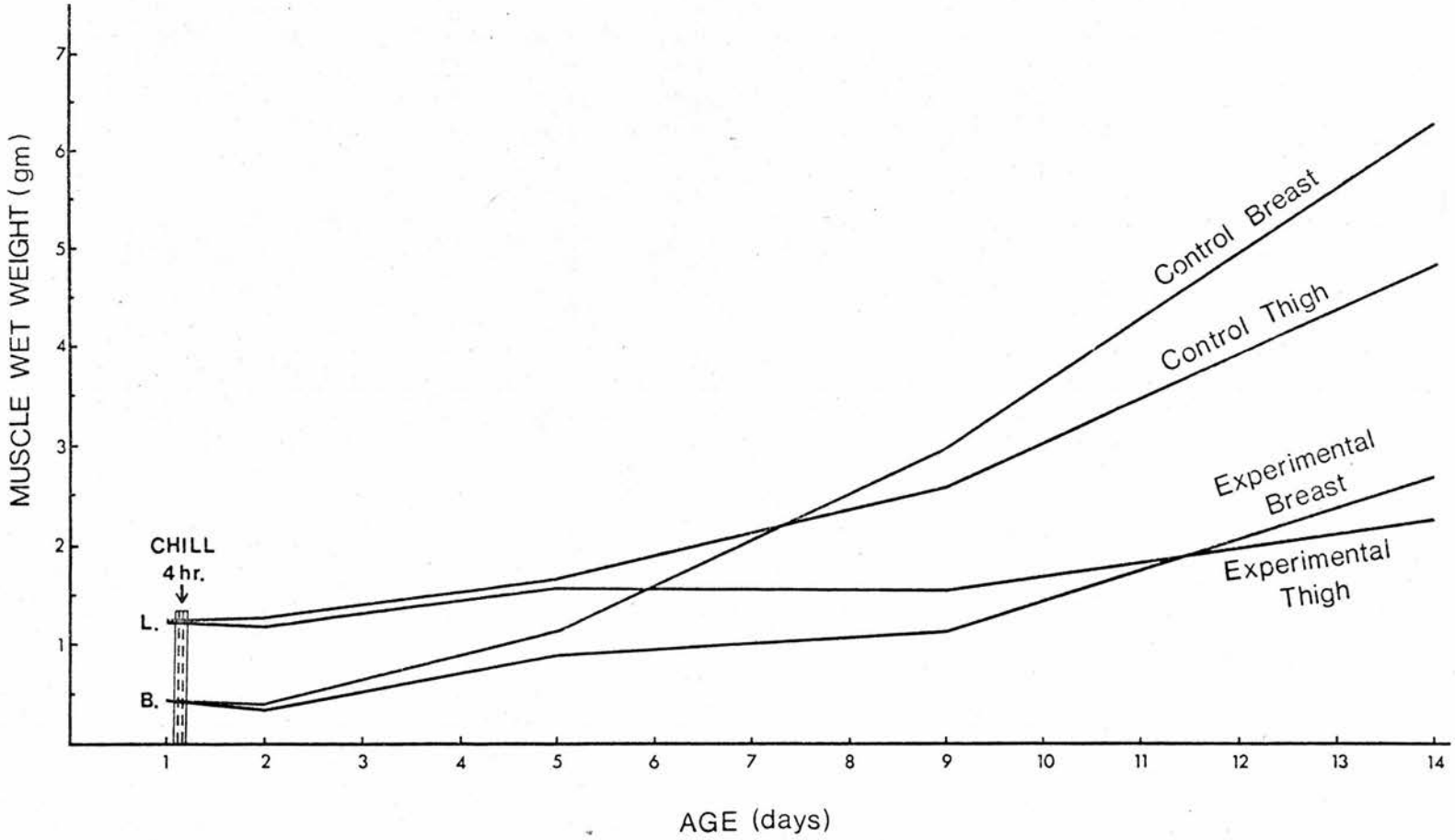

FIG. 27 Mean wet weight of breast and thigh muscles of one side of the bird at different ages. L.= Thigh muscle. B.= Breast muscle.

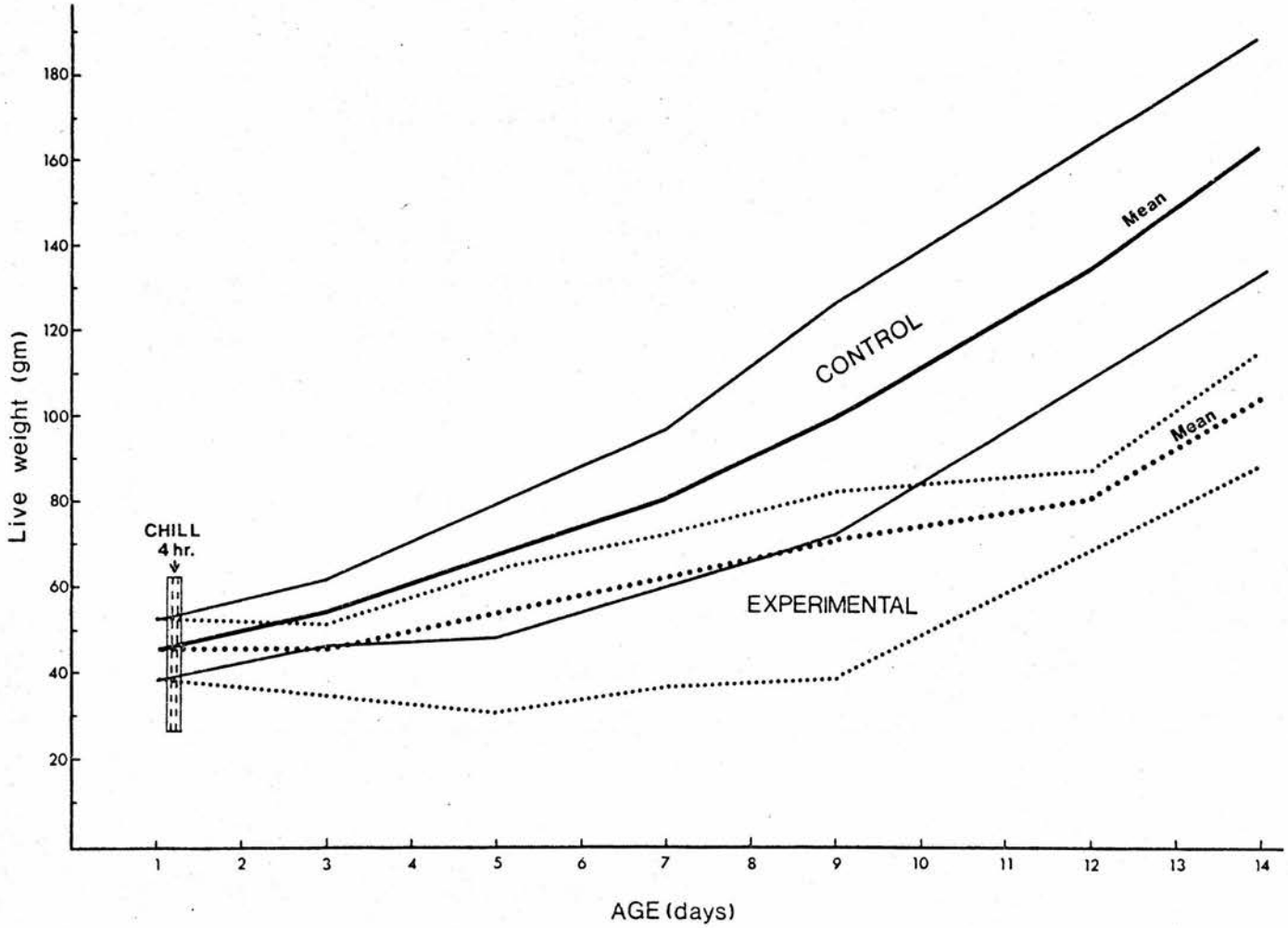

FIG. 28 Mean and range of live body weight for the control and experimental groups.

Table 28 shows the effect of cold insult on the composition of the breast and thigh muscles of the bird at different ages. The composition has been given in this table in absolute terms. Its composition includes, protein, fat, water and minerals. The latter includes the principal elements potassium, magnesium, calcium and sodium. From this table the amount of protein content of one half of the breast muscle in the normal bird at approximately one day old was 0.04 g. At the end of 14 days of age this amount increased to 1.38 g. In the experimental bird the amount of protein increased to only 0.48 g by the end of the 14 days of age. In other words, the protein content in the normal bird increased by more than 30 times within the 14 days after hatching, while the protein of the experimental bird increased by approximately 12 times. The fat content of the breast muscle of the normal chick increased by about 4 times in the newly-hatched bird up to 14 days of age. The fat content of the breast of the experimental chick increased by about 3 times from hatching to 14 days of age. Looking at the thigh muscles of both groups the protein content, potassium and magnesium were higher in the thigh muscle than in the breast muscle for approximately the first week after hatching in the control group. But in the experimental group these contents were still higher in the thigh muscle for about the first 2 weeks after hatching. This situation indicates two points: firstly, the weight of the thigh muscle as well as its composition, develops earlier than the breast

TABLE 28

Breast and thigh muscle content of protein, fat, water and minerals for control and experimental groups

Values are means of duplicate analyses from bulked material from the 12 birds in each group

Age (days)	Protein (g)	Fat (g)	Water (g)	Minerals (mg) K	Mg	Ca	Na
Breast muscle*							
Control group							
1	0.04	0.02	0.35	0.54	0.04	0.07	0.75
2	0.05	0.02	0.34	0.74	0.05	0.04	0.74
5	0.19	0.02	0.93	3.67	0.26	0.08	1.03
9	0.62	0.04	2.27	11.19	0.82	0.12	1.45
14	1.38	0.09	4.72	24.65	1.82	0.26	2.76
Experimental group							
2	0.03	0.01	0.33	0.58	0.05	0.05	0.81
5	0.13	0.02	0.75	2.65	0.18	0.04	0.87
9	0.21	0.02	0.92	3.59	0.26	0.08	0.97
14	0.48	0.03	2.10	9.98	0.62	0.10	1.68
Thigh muscle*							
Control group							
1	0.18	0.12	0.93	2.14	0.22	0.16	1.61
2	0.19	0.13	0.92	2.49	0.26	0.16	1.38
5	0.27	0.14	1.22	4.68	0.31	0.08	1.38
9	0.49	0.18	1.94	8.58	0.58	0.16	1.84
14	0.88	0.29	3.65	15.60	1.03	0.20	2.78
Experimental group							
2	0.18	0.11	0.88	2.26	0.21	0.08	1.54
5	0.27	0.13	1.18	4.68	0.35	0.09	1.33
9	0.26	0.07	1.17	5.23	0.35	0.08	1.22
14	0.38	0.09	1.73	7.84	0.56	0.07	1.56

* Breast and thigh muscle of one side of the bird only.

muscle for the first week after hatching and then the situation is reversed. Secondly, under abnormal circumstances, such as the cold effect, the breast muscle is neither higher in weight nor in composition than the thigh muscle during the first week after hatching. It took about 2 weeks in this experiment to become dominant in weight and in composition. This indicates that breast muscle has been affected much more than the thigh muscle.

Table 29 gives the same results as Table 28 but in a proportional form. Even with the elimination of the muscle weight differences the control group still has a higher proportion of protein, fat, potassium and magnesium. The experimental bird muscle is wetter than the normal bird and also has a higher percentage of sodium. Table 30 gives the composition of the body carcass of both groups. The body carcass represents the body weight minus the breast muscle and thigh muscle of one side of the body which have been dissected separately. The composition of this part of the body plus the composition of the half breast and thigh muscles gives the total composition of the whole bird. From Table 30 one can observe the effect of cold on the body carcass, weight and composition (protein, fat, water and minerals). These were all dominant in the control group but not in the experimental group. The values given in this table are expressed in absolute terms. Table 31 illustrates the protein, fat, water and mineral contents of the whole body for both groups. The control group has 5.9 g

Table 29

Breast and thigh muscle content of protein, fat, water and minerals for control and experimental groups

Values are means of duplicate analyses from bulked material from the 12 birds in each group

Age (days)	Protein g/kg w. wt.	Fat g/kg w. wt.	Water g/kg w. wt.	Minerals (mM/kg w.wt.) K	Mg	Ca	Na
Breast muscle							
Control group							
1	92	56.8	843	36.3	4.5	4.3	77.5
2	112	44.1	828	49.6	5.3	2.6	79.3
5	162	19.2	808	82.3	10.0	2.0	40.1
9	207	15.1	763	96.6	11.5	1.1	21.1
14	220	15.5	751	100.7	12.2	1.0	19.2
Experimental group							
2	80	28.4	845	39.5	4.9	3.5	90.5
5	148	20.9	878	74.2	8.2	1.1	41.5
9	169	21.0	747	80.8	9.3	1.9	36.8
14	181	11.9	783	96.1	9.6	0.9	27.7
Thigh muscle							
Control group							
1	141	98.6	746	46.3	7.3	3.2	56.9
2	156	101.5	728	51.4	8.4	3.2	50.0
5	165	83.1	737	73.1	8.0	1.3	34.1
9	188	70.2	744	83.5	9.3	1.5	30.5
14	181	60.0	750	82.7	8.9	1.2	24.8
Experimental group							
2	150	92.4	746	49.4	6.9	1.8	56.6
5	158	74.1	696	80.2	9.2	1.5	36.6
9	170	44.1	773	88.4	9.7	1.3	35.0
14	171	44.1	772	89.8	10.4	0.8	30.5

TABLE 30

Body carcass content of protein, fat, water and minerals of Control and Experimental groups

Values are means of duplicate analyses from bulked material from the 12 birds in each group

Age (days)	Protein (g)	Fat (g)	Water (g)	Minerals (mg) K	Mg	Ca	Na	P(1)	Fe
Control group									
1	5.7	2.9	30.3	67	8.2	178	58	1496	2.0
2	5.8	2.9	31.3	83	10.3	191	61	1759	4.4
5	9.0	4.1	44.7	144	16.9	298	79	2755	3.5
9	13.8	6.2	65.5	227	27.4	598	101	4681	4.0
14	23.8	13.1	104.0	367	44.2	890	177	6894	7.2
Experimental group									
2	5.8	2.7	28.7	70	7.1	164	57	1528	1.8
5	8.4	3.9	41.4	133	13.5	271	71	2557	3.2
9	10.9	3.3	50.6	152	20.0	449	80	3450	4.6
14	13.8	4.5	64.5	221	29.9	594	107	4721	5.3

(1) P has been estimated as PO_4

TABLE 31

Total body content of protein, fat, water and minerals for the Control and Experimental groups

Values are means of duplicate analyses from bulked material from the 12 birds in each group

Age (days)	Protein (g)	Fat (g)	Water (g)	Minerals (mg) K	Mg	Ca	Na	P(1)	Fe(2)
Control group									
1	5.9	3.1	31.6	69	8.5	178	60	1496	1.9
2	6.1	3.1	32.5	87	10.6	191	63	1759	4.3
5	9.5	4.3	46.8	153	17.5	299	82	2755	3.5
9	14.9	6.5	68.4	247	28.8	599	104	4681	4.0
14	26.0	13.5	112.3	407	47.0	891	182	6894	7.2
Experimental group									
2	6.1	2.9	29.9	73	7.4	165	60	1528	1.8
5	8.8	4.1	43.4	141	14.1	272	73	2557	3.2
9	11.4	3.4	52.7	161	20.6	450	82	3450	4.6
14	14.7	4.6	68.3	239	31.1	595	111	4721	5.3

(1) and (2) results are for the body carcass only

of protein at one day old which increases to 26 g at the age of 14 days. The protein rises approximately 4 times its initial weight. The situation could have been the same in the other group but, because of the effect of low temperature (10°C) on the mechanism of growth, the result was that protein increased by only twice its initial weight within the 14 days of the experiment. Fat has a different situation in the control group: fat content increased by approximately 4 times in the first 14 days of age. In the experimental group fat increased by only one and a half times its original amount within the same period. Water and minerals also increased more in the control than in the experimental group. Table 32 shows the same results as Table 31 but in proportion to the wet weight of the animal, and presents a much clearer picture than in Table 31 because of the isolation of the body weight differences. On this basis, the experimental bird appears to have a higher concentration of minerals, particularly by the end of the 14 days, and also contains a higher concentration of water. The striking point is that the concentration of protein in the control group increased from 143 g/Kg wet weight at one-day old to 166 g/Kg wet weight at 14 days old. The protein concentration of the experimental bird did not increase as much as that of the control bird. The fat proportion was remarkably decreased between one day and 14 days of age in the experimental group.

Fig. 29 shows the changes in the body protein, fat

TABLE 32

Total body content of protein, fat, water and minerals for the Control and Experimental groups

Values are means of duplicate analyses from bulked material from the 12 birds in each group

Age (days)	Protein g/kg w. wt.	Fat g/kg w. wt.	Water g/kg w. wt.	Minerals (mM/kg w. wt.) K	Mg	Ca	Na	P(1)	Fe(2)
Control group									
1	143	76	765	43.3	8.5	108	64.0	397	0.8
2	141	72	754	51.7	10.2	110	63.8	446	1.9
5	151	68	745	62.4	11.6	118	56.5	482	1.0
9	160	69	736	68.1	12.9	161	48.8	564	0.8
14	166	86	716	66.6	12.5	142	50.7	498	0.9
Experimental group									
2	155	73	765	47.9	7.9	105	66.4	428	0.9
5	153	70	750	62.5	10.1	117	55.2	487	1.0
9	170	50	782	67.4	12.7	167	53.3	590	1.3
14	160	50	744	70.7	14.1	162	52.5	572	1.1

(1) P has been estimated as PO_4. The P value is for the body carcass only

(2) Values are for body carcass only

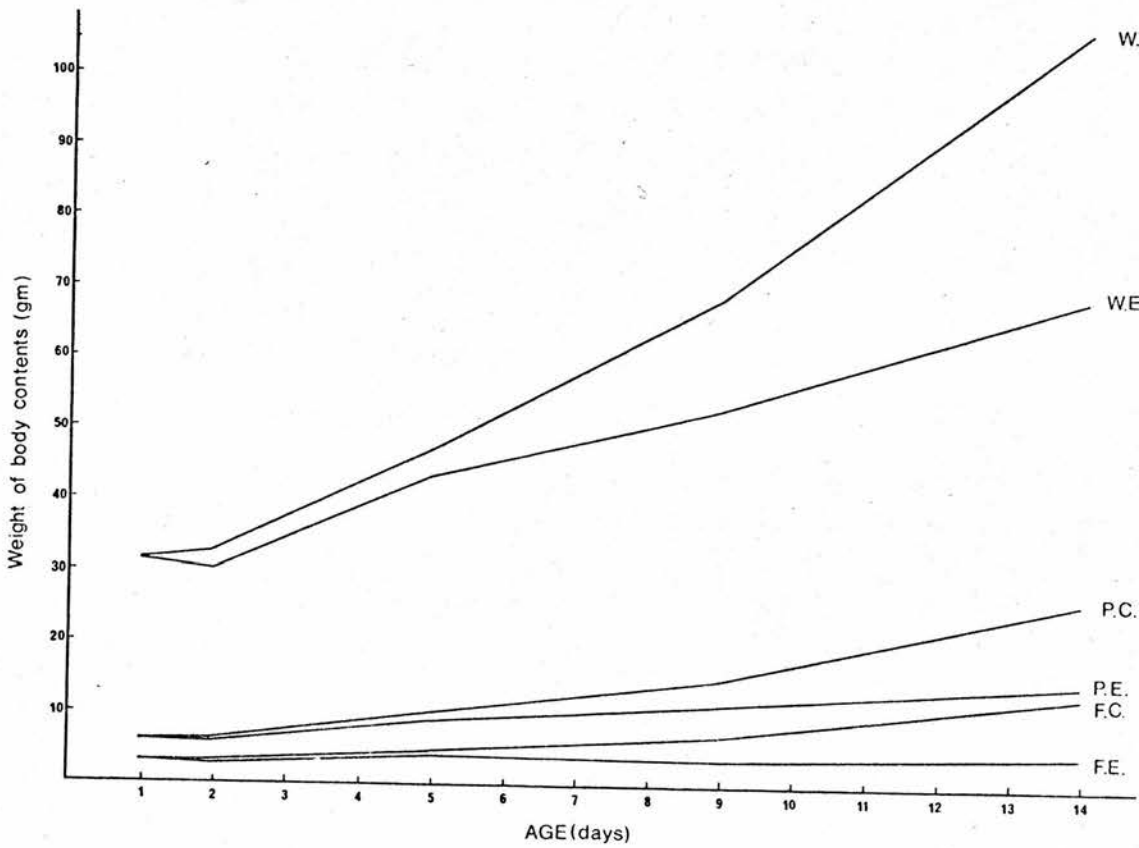

FIG. 29 Mean of body protein, fat and water contents for the Control and Experimental groups at different ages.

W.C. = Water content of the Control group.
W.E. = " " " Experimental "
P.C. = Protein " " Control "
P.E. = " " " Experimental "
F.C. = Fat " " Control "
F.E. = " " " Experimental "

and water content during different ages. Since virtually all potassium is an intracellular component, one may assume that some fraction of the muscle tissue water is extracellular. Literature suggests (Elkinton and Danowski, 1955 and Draper, 1968) and direct observation (frozen transverse section of chicken muscle) confirms that about 15% to 20% of the volume of the muscle tissue is extracellular fluid. Draper (1968) stated that histological studies of frozen sections of chicken muscle indicated that most of the fat is intracellular and that the extracellular space of muscle from newly-hatched birds differs little from that of mature muscles and is about 15% to 20% in both breast and thigh muscles. The author indicated that this proportion of extracellular space leads to a greater difference in the concentration of the intracellular ions of the muscle of the newly-hatched chick and the mature one; for example, with a 20% extracellular space the calculated K concentration in newly-hatched chick muscle would be about 60-80 mM which increases to some 160-180 mM in the mature one. According to Dickerson (1962) there is 2.9% of Ca in the fat-free chicken bones of a newly-hatched bird. This percentage increases to 6.04% at 2½ weeks of age, 6.9% at 4 weeks and 12.8% at the adult stage (27 to 42 weeks old). From the chemical analysis of fresh chicken bone presented in this work in Table 33, the proportion of Ca was found to be about 11.53% for the adult bird. This proportion is

* Dickerson (1960) found that at hatching the skeletal muscle chloride space is about 55% of the muscle tissue: in the adult bird the proportion was 12.4%.

TABLE 33

Chemical composition of adult chicken bones

The results are expressed as percentages of fresh bone

	Tibia			Femur			Sternum
	(a)	(b)	Average	(a)	(b)	Average	
Weight of fresh bone (g)	21.7	21.9	21.8	18.0	18.5	18.3	9.4*
Moisture (%)	26.4	25.2	25.8	34.5	35.2	34.9	31.2
Fat (%)	22.8	22.8	22.8	15.1	15.2	15.2	6.3
Protein (N X 6.25) %	17.9	18.2	18.1	20.3	19.2	19.8	25.6
Ash (%)	30.8	32.0	31.4	28.5	28.0	28.3	35.3
Calcium (%)	11.4	11.6	11.5	10.4	10.2	10.3	12.8
Magnesium (%)	0.155	0.159	0.157	0.144	0.142	0.143	0.167
Potassium (%)	0.084	0.090	0.087	0.135	0.133	0.134	0.140
Sodium (%)	0.295	0.295	0.295	0.277	0.273	0.273	0.313

* Part only of keel of sternum

equal to 13.50% on fat-free chicken bones. It appears, therefore, that the proportion of calcium content of chicken bone on the fat-free basis lies between 2.9 g and 13.5 g of Ca per 100 g of fat-free bones in the newly-hatched and the adult chicken respectively. Dickerson also indicated that the proportion of water of the chicken bone is 72.3% for the newly-hatched bird and 34.6% for the adult fowl, and that of the total nitrogen is 2.20% for the newly-hatched and 3.52% for the adult chicken.

From this information on bone calcium, the bone mass of the bird can be estimated accordingly. The estimations of muscle mass and bone mass have been set out in Table 34. Muscle mass has been estimated from K content of the muscle tissue: 20% of the muscle tissue has been considered as an extracellular space. Table 35 shows the effect of cold on the muscle mass, fat mass and bone mass of the fowl at different ages. There was 34.6 g of muscle mass for the newly-hatched chick of the control group. This amount increased to 91 g at the age of 14 days corresponding to a 162.6% increase. The amount of muscle mass of the experimental chick increased to only 55.8 g at the age of 14 days, corresponding to only a 61.2% increase. The fat mass of the newly-hatched chick was 3.1 g increasing to 13.5 g, which corresponds to a 331.2% increase at the age of 14 days. The fat mass of the experimental bird increased to only 4.6 g during the first 14 days of age, corresponding to an increase of only 46.5%. The bone mass

TABLE 34

The estimation of muscle mass and bone mass from potassium and calcium contents of the body

Values are means of duplicate analyses from bulked material from the 12 birds in each group

Age (days)	Amount of K (mM)	K mM/kg w. wt. of muscle tissue	Muscle tissue (g)	(1) Muscle cell mass (g)	Amount of Ca (g)	(2) Bone mass fat - free (g)
Control group						
1	1.7	41.3	43.3	34.6	0.17	6.1
2	2.3	50.5	44.1	35.3	0.19	6.6
5	3.9	77.7	50.5	40.4	0.29	6.6
9	6.3	90.0	70.4	56.3	0.59	12.0
14	10.4	91.7	113.7	91.0	0.89	14.8
Experimental group						
2	1.8	44.4	42.1	33.6	0.16	5.7
5	3.6	77.1	46.9	37.5	0.27	6.0
9	4.3	84.6	51.2	41.0	0.45	9.0
14	6.5	92.9	69.8	55.8	0.59	9.9

(1) The amount of muscle mass has been estimated on the basis that 20% of muscle tissue is extracellular water (Draper, 1968)

(2) The amount of bone mass has been estimated on the basis that fat-free bone of the newly-hatched chick contains 2.9% Ca, and that of the 2½ week old contains 6.04% Ca (Dickerson, 1962). For the 5 and 9 day old chick an approximate estimate of 4.5% and 5.0% of Ca in the fat-free bone has been considered respectively

TABLE 35

The effect of cold on muscle mass, fat mass and bone mass for a broiler type bird

Values are means of duplicate analyses from bulked material from the 12 birds in each group

	Control Group (g)			Experimental Group (g)		
Age (days)	Muscle mass	Fat mass	Bone mass	Muscle mass	Fat mass	Bone mass
1	34.6	3.1	6.2	-	-	-
2	35.3	3.1	6.6	33.7	2.9	5.7
5	40.4	4.3	6.6	37.5	4.1	6.0
9	56.3	6.5	12.0	41.0	3.4	9.0
14	91.0	13.5	14.8	55.8	4.6	9.9

has also been affected by cold but not so markedly as the fat and cell mass. In the newly-hatched bird of the control group the bone mass was 6.2 g which increased by the end of 14 days of age to 14.8 g. The weight of the bone mass more than doubled. In the experimental chick the bone mass increased to 9.9 g, as shown in Fig. 30, at the age of 14 days which is about one and a half times the initial weight. The changes which occurred in the body components as a result of this effect are discussed. Whether the effect of this particular exposure to cold on the cell growth of the fowl is permanent or not has not been studied in this work. The effect of undernutrition on cell growth has been discussed earlier in the review of literature, where it is suggested that the effect of undernutrition on cell growth and the extent to which the animal recovers depends upon the stage of development the animal has reached and on the duration of the nutritional insult (Schultze, 1955, Widdowson and McCance, 1963, Winick and Noble, 1965, Guthrie and Brown, 1968 and Widdowson, 1970). If undernutrition is experienced at the time when cell division has not ceased, the chances of recovery are very small. If the effect occurs when the cell division has ceased the animal will recover more easily (Guthrie and Brown, 1968). In the present experiment the study was concerned mainly with the effect of a short exposure to cold on animal growth. The results obtained from this work show that when the newly-hatched chick was kept at

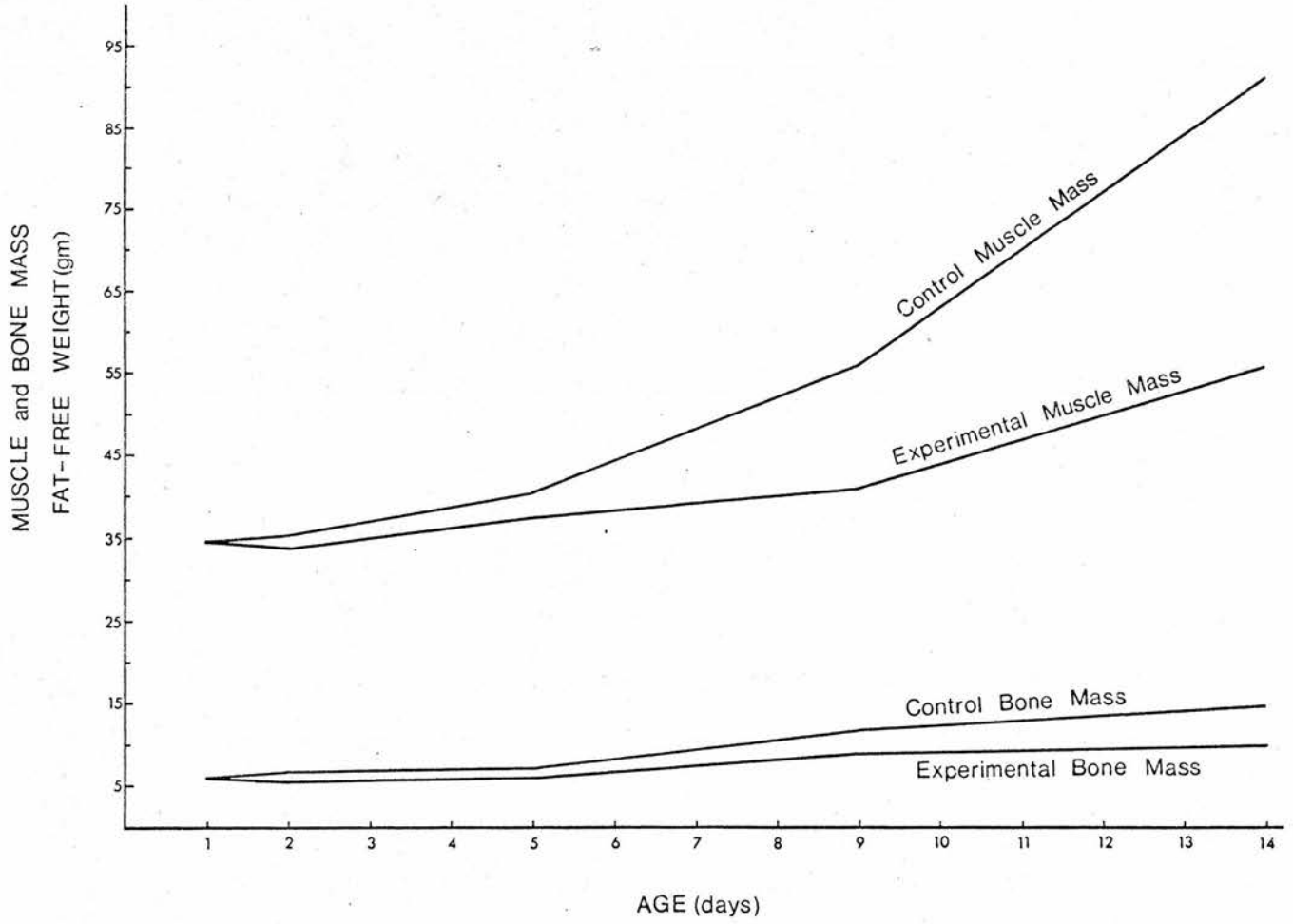

FIG. 30 Mean weight of muscle mass and bone mass fat-free during different ages.

10°C for a period of 4 hours, there was an effect on body weight and composition. This effect has been followed for 2 weeks only after hatching. The changes which occurred in the body during this effect were presented in Table 35. From this table one may observe that, in the normal bird, the quantity of muscle mass increases very rapidly during the first 14 days of age. Bone mass and fat mass also increase in quantity during the same period. In terms of percentage increase, muscle mass increases by about 163%, bone mass by about 141% and fat mass by approximately 331% within these 14 days of age. In the experimental bird the percentage increase of muscle mass was 61%, bone mass 60.7% and fat mass 46.5%.

5. GENERAL DISCUSSION

5. GENERAL DISCUSSION

The results indicate that the growth of an animal is not a simple process but a complex integration of different processes in many tissues some of which are highly active (cell mass) and some less active (adipose tissue). It would also appear that the less active tissue has the characteristic of being a store rather than a reserve tissue. Passmore and Draper (1972) define a store as a surplus of material which can be utilized without disturbing function (e.g. fat in adipose tissue). A reserve is a material which may be lost in an emergency but which must be replaced quickly if health is to be maintained (e.g. water in all tissues).

The different growth rate of body components contributes to the changing body composition as the animal ages. In the case of the domestic fowl, the composition of the body and its components have been studied at different ages in this work. Some factors have been found to bring about certain changes in the composition of the body. Some of these are environmental factors and some are associated with the actual growth and development of the animal. Sexual maturity is associated with certain changes in the body weight and its skeletal muscles, but it is not related to maturity of development in any simple way. The interpretation which one may consider as an explanation for this type of effect is that the processes of laying an egg are

not simple but are complex in nature. At this stage the activities of the ovary and oviduct are maximal. The ovary produces the ovum surrounded by yolk material and sheds it into the body cavity to be engulfed by the infundibulum. The oviduct, which begins with the infundibulum and ends with the vaginal exit into the cloaca, contributes all the coverings of the yolk mass passing through it. Each region of the oviduct has special cell constituents which make up the secretions of white albumin and the deposition of calcium carbonate on the shelled egg (Draper, 1968 and Wyburn et al, 1970). All these activities are minimal during the first 18 weeks of life (Fig. 26) and in a matter of 2 to 3 weeks the situation is explosively and dramatically changed. Since these kinds of activities indicate sexual maturity, one may not be surprised by the magnitude of the bodily changes which accompany this event. The general reaction of the body to sexual maturity and to the effect of cold has similarities. The effect brought about by a mild cold stress was marked for at least 2 weeks after hatching. Muscle mass, fat mass and bone mass were all affected. Fat mass, however, was affected much more than the other tissues of the body. Skeletal muscle was also greatly affected. This is not surprising since skeletal muscle comprises the largest cell mass of the body and undergoes chemical change more than any other soft tissue in the body. Cahill (1970) stated that when an animal utilizes some of its tissues for energy, lipid stores

are utilized primarily and, although the muscle mass is conserved, its utilization is essential for survival. This is exactly what was observed to happen in the situation of checked rapid growth, where fat was utilized more than muscle mass or bone mass. Evans (1969) studied the effect of fasting on the domestic duck (Anas platyrhynchos). He found that at the loss of 25% of the body weight as a result of fasting, the fat-free body components decreased in weight by 15.5% compared to the loss of 57.9% for fat. Others have shown that during fasting the adipose tissue mass decreases more rapidly than other tissues (Kleiber, 1961 and Grande, 1964). The significance of the cold experiment was that it showed not only the effect of cold on body growth, but also ~~demonstrated~~ suggests the value of protein and fat as a potential body fuel. Hitherto, conservation of contractile protein has been considered as a high priority for survival. In the situation described, muscle protein metabolism was greatly affected for a surprisingly long time by an apparently mild stimulus.

In the present studies breast and thigh muscles were taken as representative muscles and these were studied at different ages of the bird. They contribute in themselves a considerable fraction of the cell mass of the body and are easily identified in the domestic bird. The order in which the individual muscles develop and the extent to which they are used probably accounts for the fact that some

muscles degenerate more than others (Widdowson and Dickerson, 1964). In the case of the domestic fowl the breast muscle, which develops later and grows faster than the thigh muscle, is affected more than the thigh muscle when the fowl is under cold stress. This finding is in agreement with that reported by Dickerson and McCance (1960) who found that the pectoral muscle of the fowl was decreased more than the sartorius muscle when the bird was under-nourished. In the first week after hatching, the thigh muscle develops earlier and grows faster than the breast muscle. After approximately the first week following hatching the breast muscle grows faster and remains heavier than the thigh muscle (Table 26 and Fig. 27). Dickerson (1960) found that during the first 2½ weeks after hatching the body weight of the chick was almost doubled, but the pectoral muscle increased by about tenfold during this time. The sartorius muscle was always lighter and grew at a slower rate than the pectoral muscle. Draper (1968) gives an account for the growth of these two muscles (breast and thigh). As the domesticated chicken seldom uses its wings for flying and depends mainly on the thigh muscle for its movement, the necessity to develop the thigh muscle earlier than the breast muscle is of extreme importance for the existence of the bird, particularly in the first week after hatching. Not only the ~~relative~~ weight of the thigh muscle, but also the ~~chemical composition, was~~ content of protein, fat, K and Na were found to be greater during the first week of life. The thigh muscle contains

more protein, fat and potassium than the breast muscle for approximately the first 10 days after hatching. The situation then changes and the breast muscle contains more protein and potassium and less sodium and fat than the thigh muscle and remains so for the remainder of the bird's life. According to Bryden (1968 and 1969) the functional/demand relationship is an important factor which accounts for the pattern of growth and development of the different parts of the body. The earlier development of some tissues meets the needs of these particular tissues for their particular function at that particular stage of development. The needs for the function of the thigh muscle of the fowl, especially during the first few days after hatching, are considerable. It is also for the same reason that some tissues of the body atrophy more than others when the animal is under a particular strain. Perhaps it is understandable now why the breast muscle of the domestic fowl develops later and grows slower for the first week after hatching, then grows faster and remains heavier than the thigh muscle and also diminishes in weight and composition faster than the thigh muscle when conditions are not normal. If one can accept this as a true fact, then breast muscle of the domestic fowl must be considered to be a preferential potential reserve tissue for protein mobilisation for glucose production when food intake is greatly reduced.

From the information on the chemical anatomical composition of the bird presented in this thesis, growth has

been considered initially in terms of cell mass, fat mass, bone mass and water content. The integration of these 4 elements in the growth process of an animal is not simple and cannot easily be deduced from the live weight of the animal. From the analyses presented it is apparent that overall growth, as expressed by live weight, is no guide to the true meat content of the animal. Fat, for example, which is a significant contributor to the body weight, particularly late in life, is a chemical material which accumulates in the adipose tissue cells and thus, strictly speaking, adipose tissue is not a growing tissue.

Studying the growth of the body by the use of chemical composition is clearly more meaningful than studying growth in terms of body weight. From protein, potassium and magnesium, one can estimate cell growth; from sodium and chloride, extracellular fluid can be measured and from calcium and phosphorus skeletal mass can be estimated. Thus, one can understand the actual growth of the body and its components in terms of physiological parameters. A direct measure of cell growth is of practical interest because it gives some idea of muscle mass and this is of particular value in a carcass destined for use as meat.

It is noteworthy that, despite the different assumptions, cell mass derived from the almost completely intracellular potassium is in remarkable agreement with the calculation based on the Mg content. It is also interesting that the

disturbed growth pattern in both the cold checked growing chicken or the bird mobilising its resources for sexual productivity is faithfully reflected in the cell mass changes calculated from the K or Mg contents. This suggests that a cell mass derived from a total body K content estimated by radioactive dilution methods (Moore, 1965) could be a useful tool for studying muscle growth. If bone magnesium is slowly exchanged radioactive Mg may also be useful in cell mass studies. However, the fact that the fat synthesis in the bird is predominantly hepatic and the activity of fat deposition is accurately reflected by the fat content of the liver, may offer an easier way of choosing the best type of growth for particular purposes, e.g. a high rate of muscle growth and low fat content for the meat producing bird, or a low muscle growth and low fat accumulate in the egg producing bird.

Stress is not an easy concept to quantify. The present work at least indicates that at hatching important processes, such as muscle protein synthesis, are easily retarded. The significance of this in commercial meat producing birds could be considerable where much greater degrees of mis-handling at hatching are possible. It may well be that these effects could be greater in larger meat producing birds such as turkeys. The implications of the way sexual maturity could or need be facilitated have yet to be studied. It seems curious that a bird on an adequate/protein and

carbohydrate diet should be obliged to mobilise some of its own protein stores for the production of the sexual apparatus necessary to produce an egg. This may or may not be a "stress" phenomenon. More work is needed to clarify the situation.

Two elements of particular interest in egg production are Ca and Fe both of which are transported to the egg in biologically-speaking enormous quantities. The accumulation of these with age does seem to accelerate at sexual maturity, i.e. at 19 to 21 weeks. However, at the 23/24 week period where other tissues seem affected and growth is checked, it is interesting to see that Ca and Fe retention is also affected. From the figures available it is not easy to assess the increment of Ca retention due to egg production. Unfortunately it was not possible to carry out parallel studies in growing cockerels. However, it is clear that the increment of retention presumably for the spicular bone associated with the production of egg shells, is easily varied which is surprising in birds on a high calcium diet producing small eggs (45 g). The total body Fe appears to fluctuate somewhat similarly to the Ca content (Table 22) but the overall variation with age is too great to draw any firm conclusions other than, as expected, both minerals appear to pose problems of steady accumulation in so-called body reserves during early egg production.

6. ACKNOWLEDGEMENTS

ACKNOWLEDGEMENTS

My sincere acknowledgements to the following for their assistance throughout this work

Dr. M.H. Draper and Dr. R. Passmore for their invaluable advice and direction throughout the course of this thesis.

Mr. R. Foxton and Mr. A.A. MacKenzie for their technical assistance.

Mr. P.F. Smith for his aid in killing and dissecting the animals.

Mr. G. Anderson for carrying out the statistical analyses.

The Poultry Research Centre for providing the equipment, materials and other facilities.

The University of Libya for providing the studentship allowance.

Particular acknowledgement to my wife for her patience and understanding and for undertaking the task of typing the manuscript.

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